dcr

Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management

Water Quality Report: 2003
Wachusett Reservoir and Watershed

March 2004

ABSTRACT

The Metropolitan District Commission Division of Watershed Management (now known as the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management) was established by Chapter 372 of the Acts of 1984. The Division (now Office) was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the new Office of Watershed Management. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2003 water quality data from the Wachusett watershed. A report summarizing 2003 water quality data from the Quabbin and Ware River watersheds is also available from the Office of Watershed Management.

Acknowledgements:

This plan was prepared by the staff of the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management. Principal authors are Lawrence Pistrang, Aquatic Biologist, Wachusett/Sudbury Section and David Worden, Aquatic Biologist, Wachusett/Sudbury Section. Internal review was provided by Pat Austin. Frank Battista, John Tanona, David Worden, David Getman, and Lawrence Pistrang collected the samples and were responsible for all fecal coliform analysis.

DCR/DWSP/OWM thanks the staff and management of the MWRA Deer Island Laboratory for preparing and delivering sample bottles and performing all nutrient analyses during the year.

All maps were produced by DCR/DWSP/OWM GIS analyst Craig Fitzgerald, using the most recent data.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

WACHUSETT RESERVOIR

2003 WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	REPORTING UNITS
Temperature	degrees Centigrade
Depth	meters
Dissolved Oxygen	mg/L
Conductivity	μmhos/cm
pH	units
Alkalinity	mg/L as $CaCO_3$
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Kjeldahl Nitrogen	mg/L
Silica	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL

WACHUSETT RESERVOIR

2003 PHYTOPLANKTON DATA

PARAMETER	**REPORTING UNITS**
Plankton Concentration	Areal Standard Units per mL

WACHUSETT RESERVOIR WATERSHED

2003 TRIBUTARY WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	REPORTING UNITS
Temperature	degrees Centigrade
Depth	feet
Flow	cubic feet per second
Conductivity	μmhos/cm
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL
Metals	mg/L or μg/L

WATER QUALITY REPORT: 2003
WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Metropolitan District Commission Division of Watershed Management (now known as the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management) was established by Chapter 372 of the Acts of 1984. The Office was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Office. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2003 water quality data from the Wachusett watershed. A report summarizing 2003 water quality data from the Quabbin and Ware River watersheds is also available from the Office.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The Office and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the Office's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. The Office also samples to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from a total of nineteen stations on thirteen tributaries and from six stations on the reservoir. A sampling station at the Wachusett Dam was added to monitor water quality near the new intake location. Weekly collection of Wachusett Reservoir plankton was done from the back of the Cosgrove Intake (through early April) or from a boat at Station 3417 (Basin North) in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Weekly temperature, pH, dissolved oxygen, and conductivity profiles were taken in conjunction with plankton sampling; quarterly profiles were also measured at two additional reservoir stations. Fecal coliform samples were collected from reservoir surface stations, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

All data collected were recorded in permanent laboratory books and also as part of an electronic database (Microsoft Excel files tribs-03.xls, W_plank03.xls, 2003{_}W.xls, W_03qrt.xls, and nutrients03.xls) located at the DCR-OWM Water Quality Laboratory in West Boylston, Massachusetts. Results of tributary and reservoir water quality testing are discussed by parameter in sections 3.1 – 4.4. All water quality data are included as appendices to this report.

The Pinecroft Area drainage basin is being investigated to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Gates Brook prior to sewer construction. Weekly sampling of the Pinecroft neighborhood continued in 2003. Data collected as part of this study are included in this report. Over four hundred homes have been connected to sewers in this neighborhood in the past five years and water quality in the subbasin is expected to improve dramatically. An initial analysis is included as part of this water quality report; a more complete analysis will be completed after one more year of data collection and interpretation.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attempted to communicate with conservation commission and board of health members on a regular basis to provide technical assistance and to gain advance knowledge of proposed activities. All investigations and projects were documented as part of a comprehensive filing system.

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. Information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the fourteen subbasins within the Quinapoxet District. The information is currently under review and will be summarized in a district overview during 2004, with detailed information presented in fourteen individual subbasin chapters. Both general and specific recommendations will be developed with a proposed timeline for actions, and publication of the Quinapoxet District Environmental Quality Assessment is expected during 2004. The Thomas Basin District Environmental Quality Assessment was published under separate cover in 2003.

Samples were also collected from a number of additional locations to investigate potential water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions, usually from multiple locations on a single tributary, to help locate pollution sources. Monthly samples were collected from two stations on Gates Brook to provide baseline data for a UMASS stormwater monitoring project. All data collected are included in this report.

2.0 DESCRIPTION OF WATERSHED MONITORING PROGRAM

Wachusett Environmental Quality staff collected routine water quality samples from nineteen stations on thirteen tributaries and from six stations on the reservoir during 2003. The stations are described below in Table 1 and are located on Figure 1. Additional stations were sampled to support special studies or potential enforcement actions. Nearly 4500 samples were analyzed in-house including a total of 4334 bacteria samples and almost 100 plankton samples. More than 4000 physiochemical measurements were done in the field or at the DCR lab. In addition, seventy-one samples were collected and sent to the MWRA Deer Island laboratory for nearly 1200 analyses of nutrients and metals.

Each tributary station was visited weekly throughout the year. Temperature and conductivity were measured in the field using a Corning CD-30 conductivity meter and samples were collected for fecal coliform analysis. All analyses were done at the DCR lab facility in John Augustus Hall in West Boylston. Samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, UV-254, and total organic carbon were collected in April and October from seven stations and analyzed at the MWRA Deer Island Lab. Monthly samples for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Supporting precipitation data were gathered from NOAA weather stations in Worcester and Fitchburg, from the MWRA station at the Cosgrove Intake in Clinton, from Tower Hill in Boylston, and from the USGS station on the Stillwater River in Sterling. Fecal coliform data are interpreted in conjunction with rainfall data.

Temperature, dissolved oxygen, pH, and conductivity profiles were measured weekly at Station 3417 (Basin North) or the Cosgrove Intake in conjunction with routine plankton monitoring, and quarterly at Station 3412 (Basin South) and Thomas Basin. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, alkalinity, total phosphorus, and UV-254 were collected at the same stations from the epilimnion, metalimnion, and hypolimnion. All parameters were analyzed by the MWRA Lab at Deer Island.

Fecal coliform samples were collected daily (Monday - Thursday) from the reservoir surface at the Cosgrove Intake, the Wachusett Dam, and the Route 12 Bridge at Thomas Basin to ensure compliance with federal regulations and to help monitor the effect of weather conditions, tributary inputs, and migratory gull and geese populations on bacteria concentrations. Fecal coliform samples were also collected monthly, biweekly, or weekly at numerous locations on the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations. Twenty-three sampling locations based on reservoir configuration and flow paths were once again utilized. Sample locations are indicated on Figure 2.

TABLE 1

ROUTINE WACHUSETT SAMPLING STATIONS – 2003

STATION	LOCATION	FREQUENCY
1. Boylston Brook	Route 70, Boylston	W
2. Cook Brook (Wyoming)	Wyoming Street, Holden	W, Q
3. French Brook (70)	Route 70, Boylston	W, Q
4. Gates Brook (1)	Gate 25, W.Boylston	W, Q
5. Gates Brook (2)	Route 140, W.Boylston	W
6. Gates Brook (3)	Worcester Street, W.Boylston	W
7. Gates Brook (4)	Pierce Street, W.Boylston	W
8. Gates Brook (6)	Lombard Avenue, W.Boylston	W
9. Gates Brook (9)	Woodland Street, W.Boylston	W
10. Hastings Cove Brook	Route 70, Boylston	W
11. Malagasco Brook	West Temple Street, Boylston	W, Q
12. Malden Brook	Thomas Street, W.Boylston	W, Q
13. Muddy Brook	Route 140, W.Boylston	W, Q
14. Quabbin Aqueduct	below circular dam, W.Boylston	W
15. Quinapoxet River (dam)	above circular dam, W.Boylston	W
16. Quinapoxet River (cm)	Canada Mills, Holden	W, M, Q
17. Stillwater River (sb)	Muddy Pond Road, Sterling	W, M, Q
18. Waushacum Brook (Pr)	Prescott Street, W.Boylston	W
19. West Boylston Brook	Gate 25, W.Boylston	W, Q
A. 3409 (Reservoir)	Cosgrove Intake	D, W, Q
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	W, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	Q
D. TB (Reservoir)	Thomas Basin	Q
E. Route 12 Bridge	north side of Route 12 (Thomas Basin)	D
F. Wachusett Dam	southwest side of dam	D

D = daily (bacteria Monday – Thursday)
W = weekly (bacteria, temperature, conductivity [tributaries], algae and profiles [Cosgrove, 3417])
M = monthly (nutrients and metals)
Q = quarterly (algae and profiles [reservoir], nutrients [reservoir and tributaries])

Figure 1.

SAMPLING STATIONS

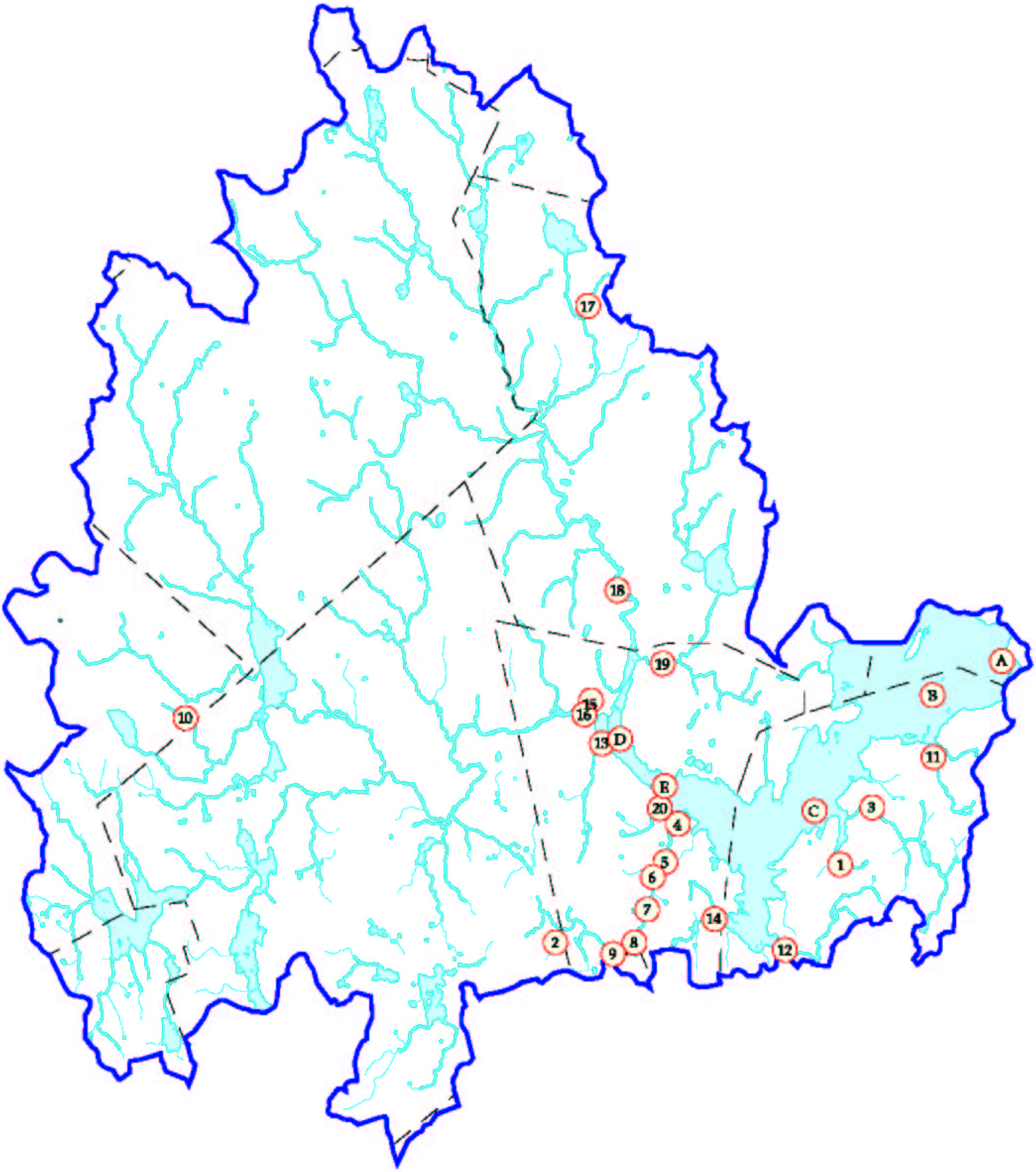


Figure 2.

RESERVOIR TRANSECT STATIONS

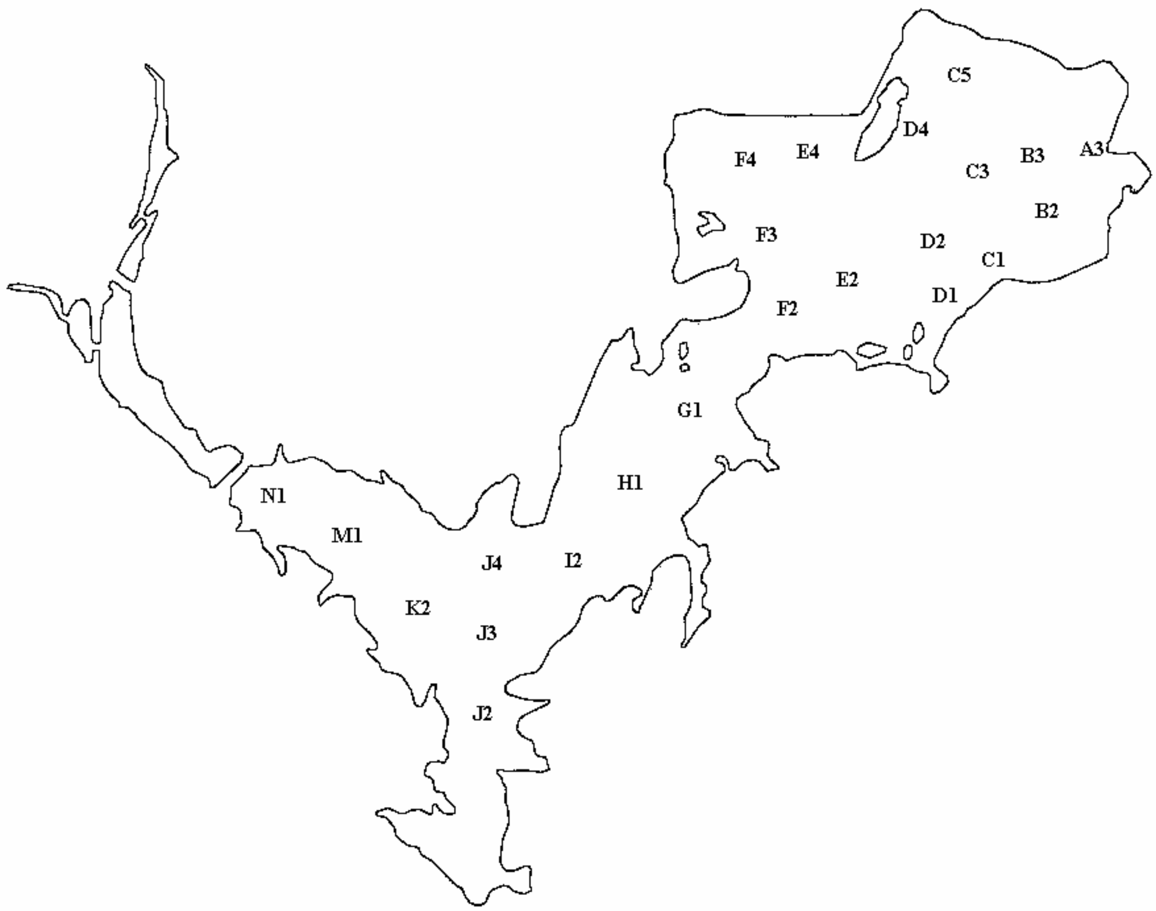


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS WACHUSETT LABORATORY

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	Corning CD-30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III Corning CD-30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Fecal Coliform	SM 9222 D
Algae	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. Phytoplankton populations in the Wachusett Reservoir were monitored at the Cosgrove Intake or from a boat at Station 3417 (Basin North) to detect increasing levels (blooms). Samples were generally collected at two depths: (1) near the middle of the epilimnion at three meters and (2) near the top of the metalimnetic interflow stratum at eight meters (also corresponding to the upper intake depth). Additionally, samples were collected at specific strata within the water column supporting intense growth or activity by phytoplankton as indicated by spikes in dissolved oxygen concentrations (a “positive heterograde curve”) measured in the field with a Hydrolab multiprobe.

Routine macrophyte (rooted aquatic plant) surveys of Wachusett Reservoir were initiated by DCR staff in 1999. Detection of alien species and characterization of the reservoir macrophyte community are the main goals of survey efforts. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum*) was observed for the first time in Upper Thomas Basin. The expansion of milfoil into this area represented a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. This prompted DCR to design a milfoil control program which was implemented in 2002. Milfoil control efforts in 2003 consisted of a continuation of hand-harvesting as well as implementation of biological control using the milfoil weevil. Details of the 2003 program are summarized in Section 4.5.

3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

3.1 BACTERIA

Fecal coliform concentrations were measured as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Total coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as "facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that develop red colonies with a metallic golden sheen within 24 hours at 35° C on an Endo-type medium containing lactose". Fecal coliform are a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Both groups of bacteria are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of any coliform bacteria in drinking water suggests that there may be disease-causing agents present as well.

Fecal coliform concentrations were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established in 314 CMR 4.00 state that "fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL". Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at eighteen of nineteen tributary stations (95%). Only the Quabbin Aqueduct had an annual mean value less than the standard. More than 10% of the samples collected exceeded 100 colonies per 100 mL at all but four of the stations (Muddy, Malden, Waushacum, and Quabbin Aqueduct).

One or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values often increase by several orders of magnitude following storm events or during periods of high groundwater. An alternate way of looking at summary data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values to represent water quality has been used for many years by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries.

Precipitation data from weather stations in Worcester, Fitchburg, Boylston, Clinton, and Sterling were used in 2003 to help segregate water quality samples impacted by storm events from those more representative of baseline conditions. As expected, storm events appear to have a significant impact on fecal coliform concentrations. Data in Tables 4-6 illustrate the importance of major precipitation events and also highlight tributaries where conditions are poor even during dry weather. The tables show both the immediate effect of storm events on water quality and also the lingering impacts over the several days following a storm. Various summary statistics respond differently to storm events and are discussed below.

TABLE 3

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2003)	MEDIAN (2002)	SAMPLES
Boylston Brook	14400	<10	405	35	10	50
Cook Bk. (Wyoming)	17000	<10	637	20	20	51
French Brook (70)	4000	<10	151	20	10	51
Gates Brook (1)	10000	<10	553	20	10*	50
Gates Brook (2)	15000	<10	667	40*	50	51
Gates Brook (3)	53000	<10	1440	30	40	51
Gates Brook (4)	39000	<10	1446	30*	50	51
Gates Brook (6)	14000	<10	675	30*	50	51
Gates Brook (9)	890	<10	84	30	20	51
Hastings Cove Brook	4300	<10	181	20	<10	45
Malagasco Brook	10200	<10	332	20	20	51
Malden Brook	500	<10	39	10	10*	51
Muddy Brook	1600	<10	68	20	10	51
Quabbin Aqueduct	12	0	1	0	0	23
Quinapoxet River (dam)	600	<10	97	30	n/a	34
Quinapoxet River (cm)	2100	<10	158	40	40	51
Stillwater River (sb)	900	<10	87	30	20	51
Waushacum Brook (Pr)	670	<10	51	20	20	50
West Boylston Brook	18000	<10	698	30*	40	50

*below historic levels

Mean fecal coliform concentrations in 2003 were considerably higher than normal due to extremely high maximum values at most stations recorded during storm events in September and October. Median fecal coliform concentrations in 2003 were comparable to those measured during 2002. Five stations (West Boylston and Gates 2, 3, 4, and 6) showed some improvement, while six (French, Gates 1, Gates 9, Hastings Cove, Muddy, and Stillwater) had slightly higher median concentrations. Four of the sampling stations with improved water quality (West Boylston and Gates 2, 4, and 6) recorded their lowest median concentration ever, and several others were at or near record lows as well. Boylston Brook, however, had its highest median fecal coliform concentration since 1992 and nearly its highest ever. Additional work was done to locate the source of the problem on Boylston Brook. UMASS researchers used alternative indicator organisms to determine that the fecal bacteria are likely of human origin, and the Boylston Board of Health has identified two homes with inadequate septic systems. DCR staff are working with the Board of Health to remediate the problem.

When the tributaries are ranked using annual mean values, stations on Gates Brook have four of the five highest concentrations of fecal coliform, just as they did in 2002. West Boylston Brook also is one of the worst, with an annual mean lower only than Gates 4 (Pierce Street) and Gates 3 (Worcester Street). Cook Brook, Gates 1, Boylston Brook, Malagasco Brook, and the Quinapoxet River at Canada Mills complete the top ten list.

The use of median values instead of mean values reduces the impact of storm events by suppressing the significance of intermittent extreme concentrations and in doing so often changes tributary rankings. Gates 2 (only 5th highest when ranked by annual mean) and the Quinapoxet River (10th highest) tied for the highest annual median value. Boylston Brook was the 3rd highest, and seven stations followed close behind (Gates 3, 4, 6, and 9, West Boylston Brook, the Stillwater River, and the Quinapoxet River (circular dam site). This suggests that contamination at Gates 2 and at the Quinapoxet River at Canada Mills was consistent, while problems at some of the other stations were periodic in nature.

TABLE 4

MEAN FECAL COLIFORM – EFFECT OF >0.5” STORMS (colonies/100 mL)

STATION	**MEAN**	**MEAN** no storm samples	**MEAN** no samples w/i 24hrs	**MEAN** no samples w/i 72hrs
Boylston Brook	405	48	36	35
Cook Bk. (Wyoming)	637	47	39	34
French Brook (70)	151	64	52	47
Gates Brook (1)	553	50	40	31
Gates Brook (2)	667	134	126	133
Gates Brook (3)	1440	53	38	30
Gates Brook (4)	1446	133	98	100
Gates Brook (6)	675	174	145	154
Gates Brook (9)	84	38	34	30
Hastings Cove Brook	181	29	28	29
Malagasco Brook	332	81	72	63
Malden Brook	39	27	15	15
Muddy Brook	68	33	29	28
Quinapoxet River (dam)	97	53	33	29
Quinapoxet River (cm)	158	55	44	42
Stillwater River (sb)	87	47	31	27
Waushacum Brook (Pr)	51	29	28	20
West Boylston Brook	698	65	48	45

Mean values are strongly impacted by rainfall events as illustrated by Table 4. Annual mean values decline significantly when all samples collected during storm events of 0.5 inches or more were excluded. Fecal coliform concentrations in the tributaries are suspected to continue to decline for several days following a rain event, although not enough data were collected to confirm this. A single storm event during the early summer was sampled; two stations on Gates Brook exhibited a decline in fecal coliform concentrations over a four day period. Concentrations at Gates 2 dropped from 1200 to 570 to 290 to 170, while concentrations at Gates 3 declined in a similar fashion from 2200 to 610 to 350 to 200. Stormwater sampling will be done during 2004 to gather additional data from a range of tributaries, and samples will be collected for several days following each storm to document temporal changes in fecal coliform concentrations.

TABLE 5

MEDIAN FECAL COLIFORM – EFFECT OF >0.5" STORMS
(colonies/100 mL)

STATION	**MEDIAN**	**MEDIAN** no storm samples	**MEDIAN** no samples w/i 24hrs	**MEDIAN** no samples w/i 72hrs
Boylston Brook	35	20	20	20
Cook Bk. (Wyoming)	20	20	10	10
French Brook (70)	20	10	10	5
Gates Brook (1)	20	10	10	10
Gates Brook (2)	40	30	30	30
Gates Brook (3)	30	20	20	20
Gates Brook (4)	30	25	20	15
Gates Brook (6)	30	30	20	20
Gates Brook (9)	30	25	20	15
Hastings Cove Brook	20	10	10	5
Malagasco Brook	20	20	20	15
Malden Brook	10	5	5	5
Muddy Brook	20	10	10	10
Quinapoxet River (dam)	30	30	20	20
Quinapoxet River (cm)	40	40	20	10
Stillwater River (sb)	30	20	20	20
Waushacum Brook (Pr)	20	10	10	10
West Boylston Brook	30	30	25	20

Median fecal coliform concentrations were not strongly affected by rainfall (Table 5). Annual median values did not decline significantly when samples collected during storm events of 0.5 inches or more were excluded. This would seem to confirm that median values give a better representation of 'average' conditions in these tributaries throughout the year by eliminating the importance of extremely high concentrations ('spikes'). The relationship between fecal coliform 'spikes' and rainfall is shown in Table 6.

TABLE 6

FECAL COLIFORM SPIKES – EFFECT OF >0.5" STORMS (colonies/100 mL)

STATION	%>20/>100	%>20/>100 no storm samples	%>20/>100 no samples w/i 24hrs	%>20/>100 no samples w/i 72hrs
Boylston Brook	54/22	49/16	43/8	40/9
Cook Bk. (Wyoming)	49/18	43/11	37/10	33/8
French Brook (70)	45/20	41/13	37/10	28/6
Gates Brook (1)	40/18	33/9	33/8	29/6
Gates Brook (2)	63/27	59/20	56/15	58/14
Gates Brook (3)	53/16	48/7	46/2	44/0
Gates Brook (4)	55/31	50/24	44/20	42/17
Gates Brook (6)	59/13	54/24	49/20	44/19
Gates Brook (9)	55/12	50/2	46/0	42/0
Hastings Cove Brook	36/11	30/5	25/6	26/6
Malagasco Brook	49/35	43/28	41/24	39/25
Malden Brook	27/8	20/4	15/2	14/3
Muddy Brook	45/10	39/7	37/5	36/6
Quinapoxet River (dam)	59/26	52/14	48/4	45/0
Quinapoxet River (cm)	57/24	52/15	46/12	42/11
Stillwater River (sb)	51/22	46/13	39/7	33/6
Waushacum Brook (Pr)	44/10	38/4	35/5	29/0
West Boylston Brook	58/20	53/11	50/8	49/9

The percentage of samples exceeding twenty colonies (or one hundred colonies) declines when storm samples are excluded from the database, and at most stations drops even more if samples collected within a day are not considered as well. Any interpretation on annual data must take into account all available precipitation data to ensure that any comparisons or trends are actually valid.

Multiple sampling stations on Gates Brook have been utilized for many years in order to help locate sources of fecal contamination. Gates Brook remains one of the most contaminated tributaries in the watershed, although water quality is beginning to improve as an increasing number of homes are connected to the new municipal sewers. The results from the six stations are variable, with Gates 4 having the highest annual mean and Gates 2 the highest annual median. If you remove the influence of storm events Gates 6 has the highest annual mean and one of the highest annual medians. The lowest annual mean (with or without storm events) was at Gates 9; the lowest annual median regardless of weather was at Gates 1. Gates 2 and 6 had the most samples with more than 20 colonies per 100mL, while Gates 4 and 2 contained the most exceeding 100 per 100mL.

Historical data were examined to detect any long-term water quality trends. Most of the sampling stations had below normal annual median fecal coliform concentrations, including all stations on Gates Brook as well as stations on Cook, Malagasco, Malden, and West Boylston Brooks. French Brook, Waushacum Brook, and the Stillwater River had concentrations similar to previous years, although French Brook water quality appears to be declining as a result of the continued presence of beaver just upstream of the sampling location. Median fecal coliform concentration in the Quinapoxet River remains elevated; a larger number of samples from 2003 contained more than 20 colonies per 100mL than in any previous year. An Environmental Quality Assessment of this subbasin was done in 2003 and sources of contamination will be addressed in that report. Muddy Brook, Hastings Cove Brook, and Boylston Brook also had elevated fecal coliform concentrations that were much higher than normal, and staff are attempting to determine the cause. The source of contamination in Boylston Brook has been located and remediation efforts are underway as described above.

Samples were collected from five stations on Malagasco Brook, four stations on Beaman Pond Brook, three stations on Oakdale Brook, and two stations in the Crescent subbasin to investigate potential water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations (see Table 7 for summary data). Water samples were collected during both dry and wet conditions. Monthly samples were also collected from two stations on Gates Brook to provide baseline data for a UMASS stormwater monitoring project, and an additional eighty stormwater samples from these stations were analyzed at the DCR lab facility in John Augustus Hall in West Boylston.

TABLE 7

FECAL COLIFORM – SPECIAL STATIONS
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	SAMPLES
Malagasco 1	6800	<10	392	75	86	36
Malagasco 2	8000	<10	530	180	83	36
Malagasco 3	8400	<10	685	155	89	36
Malagasco 4	8300	<10	702	140	78	36
Malagasco 5	4700	<10	460	105	78	36
Beaman 1	4100	<10	480	190	80	15
Beaman 2	1000	<10	189	110	74	27
Beaman 3	7500	<10	865	150	73	26
Beaman 4	120	<10	25	10	14	7
Oakdale 1	6800	<10	514	40	60	15
Oakdale 2	450	<10	103	28	50	6
Oakdale 3	300	<10	60	15	17	6
Crescent (elem)	10	<10	6	5	0	6
Crescent (Rt.12)	60	<10	24	20	29	7

Interpretation of data from Malagasco Brook is difficult. Station #4 had the highest annual mean fecal coliform concentration, but Station #2 had the highest annual median and Station #3 had the most samples exceeding 20 colonies per 100mL. The same is true if samples collected within twenty-four hours of a significant storm (0.5" or more) are excluded. It appears that contamination of Malagasco Brook is variable and from multiple sources.

A better way of looking at the data is to compare results by date at the five stations. Samples were collected twice weekly from Station #1 (once as part of the routine sampling program and once for this special study), but only the 'special study' samples that were collected in conjunction with the other four stations were used for this analysis. Station #3 (located within a townhouse complex) had the highest fecal coliform concentration on eighteen of thirty-six sampling days, more than twice as often as any of the other stations (see Table 8). It also had the highest concentrations during or following storm events, and when fecal coliform levels were relatively low. It appears clear that contamination of the tributary is entering the water upstream of Station #3, possibly from septic systems serving the townhouse complex.

TABLE 8

HIGHEST DAILY FECAL COLIFORM CONCENTRATION

STATION	**All Samples**	**Storm Samples**	**Samples With < 100 Colonies**
Malagasco 1	2	0	2
Malagasco 2	4	2	1
Malagasco 3	18	5	3
Malagasco 4	5	2	2
Malagasco 5	8	2	0

Students from the University of Massachusetts and Worcester Polytechnic Institute working on an independent study and a major qualifying project collected samples of a variety of indicator organisms and drew similar conclusions. The students examined historical data and gathered new data from six sites. Their results suggest that the primary source of contamination is located within the vicinity of the townhouse complex. Complete analysis of these samples will be available in a separate report from the two institutions.

Data from Beaman Pond Brook were easier to understand. Samples were not collected from Station #1 (downstream) and Station #4 (upstream) as often as samples from Station #3 (horses) or Station #2 (houses) due to seasonal low flow conditions. They were therefore excluded from a direct comparison with the other two stations. Station #3 had a higher annual mean and median fecal coliform concentration than Station #2, and had the highest fecal concentration of the two stations on sixteen of twenty-four days. Station #3 is directly downstream of a property with horses, and no management practices are currently being used by the owners to keep the manure away from the brook. It is clear that activities on this property are contaminating Beaman Pond Brook.

Oakdale Brook was sampled initially at three locations and then at a single station for a portion of 2003. Fecal coliform concentrations remain higher than desirable, and it appears that the source of contamination is located upstream. Additional sampling is recommended. This subbasin has recently been sewered and fecal coliform concentrations in the stream should decline once homes are connected and septic systems abandoned.

Samples from a small tributary in the Crescent subbasin contained very low levels of fecal coliform and no source of contamination is apparent. A pumping station for the municipal sewer is currently undergoing construction in this subbasin. The sewer and an associated stormwater control structure should help further reduce fecal coliform concentrations.

Monthly samples were collected from two stations on Gates Brook to provide baseline data for a University of Massachusetts stormwater monitoring project. Samples collected during dry weather in the winter, spring, and late fall contained low concentrations of fecal coliform, but concentrations were elevated in samples collected during the summer and early fall. Five storm events (average duration of twelve hours) were sampled by university students and staff and eighty stormwater samples were filtered, incubated, and counted at the DCR lab facility in West Boylston. Sampling location, time of year, and the amount of rainfall appear to all impact fecal coliform concentrations (preliminary data are included in Table 9 below).

TABLE 9

FECAL COLIFORM CONCENTRATION – GATES BROOK
(colonies/100 mL)

DATE OF STORM	LOCATION	AMOUNT OF RAIN	RANGE OF FECAL COLIFORM
2/4/03	urban	0.2 – 0.4	30 – 1100
	agriculture		<10 – 40
5/2/03	urban	0.2 – 0.6	<10 – 380
	agriculture		<10 – 110
8/1/03	urban	0.5 – 0.6	1400 – 23,800
	agriculture		600 – 5800
9/2/03	urban	0.3 – 0.8	<100 – 14,000
	agriculture		<100 – 3700
12/11/03	urban	0.8 – 1.1	<10 – 360
	agriculture		20 – 480

Samples for nutrients, alternative indicator organisms, and the protozoa *Cryptosporidium* and *Giardia* were also collected during storm events. Routine monthly sampling and additional storm event sampling will continue until the summer of 2004, and a complete write-up of the study will be available from the University of Massachusetts.

Additional samples are collected from tributaries when fecal coliform concentrations are abnormally high and there is no obvious cause. A sample collected at Gates 2 (Route 140) on June 17th contained more than 2000 fecal coliform per 100mL, but a sample from the closest station upstream contained only ninety. Scarlett Brook is tributary to Gates Brook between these two stations. Samples were collected from both tributaries the following week and fecal coliform concentrations were elevated at both stations as well as at upstream stations on Gates Brook. A significant rain event (2") had taken place twenty-four hours earlier and fecal coliform concentrations were elevated at most sampling station in the watershed, so determining the source became difficult. Samples were collected for several consecutive days, and concentrations declined at all stations but remained higher than normal. Samples were also collected for the next few weeks in Gates Brook and at various locations in Scarlett Brook; it was eventually determined that the contamination must have originated at or near the WalMart Plaza. Fecal coliform concentrations were back to normal by early July and nothing further was done to investigate the problem.

A sample collected at Gates 2 on November 25th contained 180 fecal coliform per 100mL, and a sample from Gates 3 upstream contained less than ten. By the following week the source of the problem was apparent. The new municipal sewer line on Worcester Street was discovered to have developed a leak just upstream of Gates 2 and untreated sewage was reaching the brook. A sample collected on December 3rd at Gates 2 contained nearly 12,000 fecal coliform per 100mL, and similar concentrations were measured at Gates 1 near the reservoir on the same day. It is unclear how long the leak existed before it was detected. Frozen soil forced the sewage to the surface where it was easily discovered in November, but it is very possible that some contamination was reaching the tributary intermittently during the summer and fall when it could still pass through unfrozen soil. This would explain the data anomaly detected in June. The cracked pipe only carries sewage when enough has reached the pump station on Route 140 and it is necessary to pump it back uphill towards Worcester, so any contamination would be irregular and difficult to detect. The pipe was repaired immediately following discover of the leak and no further problems have been noted.

Fecal coliform samples have been collected from stations on Cook Brook for the past six years to evaluate the impacts of sewering on water quality. Cook Brook flows through the Pinecroft neighborhood of West Boylston and Holden, an area known for numerous problems with outdated or inadequate septic systems. A decision was made in the late 1990s to replace the septic systems with a municipal sewer system. Fecal coliform data were collected in 1998 prior to sewer construction, and weekly data collection has continued through 2003. Over four hundred homes have been connected to sewers in this neighborhood during the past five years. Initial results seem to show improvements to water quality as a result of the new sewers, with annual median fecal coliform concentration declining from pre-sewer conditions. The percentage of samples exceeding 20 colonies per 100mL has also declined since sewers were installed and homes were connected. Data are illustrated in Table 10 on the following page.

TABLE 10

FECAL COLIFORM – COOK BROOK (January-December)
(colonies/100 mL)

	1998	1999	2000	2001	2002	2003
	pre-sewer					
Annual Median	41	25	18	50*	20	25
% samples>20	70	55	47	54	35	50
# of Samples	50	42	49	39	43	50
Annual Rainfall	47.0"	41.3"	44.3"	**33.3"**	44.0"	50.6"

Annual median coliform concentration is considerably lower in four of the five years following sewer installation. Data from 2001 appear to show a return to poor water quality, but a closer look provides an explanation. Total rainfall in 2001 was more than ten inches below average, and in particular the summer and fall were extremely dry. Cook Brook was only sampled on three dates after September 4th because of low flow or no flow conditions. Fecal coliform concentrations generally decline in Wachusett watershed tributaries during the late fall and early winter, and not sampling during this time period would increase the annual median value. In addition, the few dates that were sampled during the fall were following storm events that produced enough flow to allow sampling, but also contained higher levels of fecal coliform than seen during dry weather. Sampling only following storm events will artificially increase annual median values. A comparison of fecal coliform data from Cook Brook that excludes fall samples supports these statements.

TABLE 11

FECAL COLIFORM – COOK BROOK (January-September 5)
(colonies/100 mL)

	1998	1999	2000	2001	2002	2003
	pre-sewer					
Annual Median	48	24	12	30	20	30
% samples>20	72	55	40	50	42	53
# of Samples	36	29	35	36	33	36

Contaminated stormwater remains a problem in this subbasin and may continue to pollute the stream even after sewer hookups are completed. A more complete analysis will be completed after one more year of data collection and interpretation.

3.2 NUTRIENTS

Samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, UV-254, and total organic carbon were collected in April and October from seven tributary stations and analyzed at the MWRA Deer Island Lab using methods with low detection limits. Monthly samples for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements were determined each week using staff gages and USGS rating curves. All data collected are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries ranged from 0.005 mg/L NO_3-N to 3.63 mg/L NO_3-N. Nitrate levels are usually highest in Gates and West Boylston Brooks and are usually significantly elevated with respect to the other tributaries and the reservoir. This was true once again in 2003. Elevated nitrate levels in these two brooks are expected because of the high number of improperly functioning septic systems and the density of development in these subbasins.

TABLE 12

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.028	0.994	0.096	3.63	3.54	0.491	0.490	0.420
MIN	0.005	0.476	0.077	2.31	3.25	0.408	0.208	0.166
MEAN	0.017	0.735	0.087	2.97	3.40	0.450	0.378	0.310

Nitrate-nitrogen concentrations observed during 2003 were within historic ranges in most tributaries. The maximum value recorded in Gates Brook was the highest ever, however, and the other sample collected from the brook had a higher concentration than all but three samples collected over the previous five years. It is clear that the positive impacts of sewers relative to nutrient loading are not yet being observed in this tributary, and in fact it is possible that problems with the new sewer could be responsible for the elevated concentrations. Nitrate concentrations observed in the Stillwater River were also higher than seen previously, and an examination of the data from the past five years suggests that concentrations are rising annually. An Environmental Quality Assessment of the Stillwater subbasin planned for 2004 may help locate the source of this nutrient.

Concentrations are usually higher in Cook Brook than in any of the routine tributaries sampled during the year, with an annual mean concentration more than double than what is found in Gates or West Boylston Brooks. This was not the case in 2003, although any analysis based on only two samples is premature. The Cook Brook subbasin has recently been sewered and improvements to water quality are expected, although not are apparent at this time. Additional samples will be collected to document any long-term changes to annual nitrate-nitrogen concentrations.

TABLE 13

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming
						pre-sewers
YEAR	2003	2002	2001	2000	1999	1998
MAX	4.78	4.63	4.59	5.82	4.52	3.44
MIN	1.90	4.39	1.98	2.18	2.94	1.60

Nitrite-nitrogen was detected at very low concentrations, with a maximum recorded value of 0.012 mg/L measured in April at Cook Brook. All samples from French, Malagasco, Muddy, Gates, West Boylston, and Malden Brooks had concentrations below the limits of detection (0.005 mg/L). Only three of thirty-eight samples (the sample from Cook Brook and one sample each from the Quinapoxet and Stillwater Rivers) contained detectable concentrations of nitrite-nitrogen.

Ammonia was detected in most tributaries and generally at normal concentrations, although the maximum values recorded from French and Cook Brooks were the highest ever. Concentrations in Gates and Malden Brooks were lower than historical values. It should again be pointed out that interpretation of annual data using only two data points must be done cautiously.

TABLE 14

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK
MAX	0.204	0.020	0.053	<0.005	0.092	0.009	0.078	0.040	0.117
MIN	0.045	0.005	0.007	<0.005	0.009	<0.005	<0.005	<0.005	<0.005
MEAN							0.045	0.018	

Phosphorus is an important nutrient, and has been determined to be the limiting factor controlling algal productivity in the Wachusett Reservoir. EPA Water Quality Criteria (1976) recommended a maximum concentration of 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving waterbodies. Concentrations measured in the Wachusett tributaries ranged from 0.009 mg/L to 0.099 mg/L total P during 2003. Concentrations were comparable to those seen last year and lower than previous years in all tributaries except in French Brook and West Boylston Brook. Concentrations were higher in these two tributaries, although only two samples were collected from each station. Only four of thirty-four samples collected (three from the Stillwater River, one from French Brook) exceeded the recommended concentration.

TABLE 15

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.099	0.027	0.012	0.025	0.050	0.037	0.039	0.067
MIN	0.020	0.021	0.009	0.016	0.012	0.009	0.015	0.015
MEAN							0.023	0.037

Data from Cook Brook in the Pinecroft neighborhood (Table 16) appear to show improvements to water quality as a result of the new sewers. Total phosphorus data were collected in 1998 prior to sewer construction, and data collection has continued through 2003. Over four hundred homes have been connected to sewers in this neighborhood during the past five years. Maximum concentrations declined each year through 2002; future improvements may be minimal as most homes are now connected. Fecal coliform data illustrated in Table 10 showed similar improvements.

TABLE 16

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming
						pre-sewer
YEAR	2003	2002	2001	2000	1999	1998
MAX	0.033	0.031	0.053	0.095	0.170	4.74
MIN	0.009	0.021	0.012	0.008	0.012	0.009

Silica concentrations ranged from a low of 2.59 mg/L in April (French Brook) to a high of 11.6 mg/L in October (West Boylston Brook). The annual mean concentration in the watershed during 2003 was 7.39 mg/L, virtually identical to the annual mean of 2002. Concentrations were similar throughout the watershed. Cook Brook had the highest annual mean concentration, while the Quinapoxet River and French Brook had the lowest. Low concentrations were measured in the Stillwater River as well.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2μm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in Wachusett tributaries ranged from <5 mg/L to 21.0 mg/L, with twenty-seven of thirty-eight samples containing less than the detection limit. High suspended solids were measured during June and December in samples from the Quinapoxet River and during May, July, October, and December in samples from the Stillwater River. All other samples with detectable levels of total suspended solids contained less than 10 mg/L.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.56 to 26.3 mg/L, with an overall mean value of 5.35 mg/L. The highest readings were recorded from Malagasco and French Brooks and the lowest from Gates Brook. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks.

Concentrations of twenty-one metals were measured in samples collected from the Stillwater and Quinapoxet Rivers each month. No antimony, beryllium, selenium, silver, or thallium were detected in any samples, and arsenic, cadmium, chromium, copper, lead, mercury, and nickel were present at very low concentrations (less than 10 μg/L). Barium and zinc were present in slightly higher concentrations but averaged less than 25 μg/L . Aluminum, calcium, iron, magnesium, manganese, potassium, and sodium were present at higher concentrations (see Table 17), but in all cases were at lower concentrations than recorded during 2002. The only significant difference between the two rivers continues to be in the amount of sodium present; concentrations in the Quinapoxet were nearly twice the concentration measured in the Stillwater and likely reflect the greater degree of development and elevated amounts of road salt used in the Quinapoxet River subbasin.

TABLE 17

METALS CONCENTRATIONS (mg/L) – annual mean and range

station	Al	Ca	Fe	Mg	Mn	K	Na
QUINAPOXET	0.11	7.92	0.37	1.45	0.08	1.70	26.4
range	0.25 - 0.05	8.71 - 6.24	0.63 - 0.14	1.64 - 1.18	0.14 - 0.04	2.04 - 1.56	29.6 - 18.7
STILLWATER	0.17	6.40	0.43	1.16	0.07	1.34	16.6
range	0.40 - 0.07	10.4 - 4.20	0.80 - 0.17	1.80 - 0.89	0.13 - 0.04	2.20 - 0.98	23.7 - 11.5

3.3 SPECIFIC CONDUCTANCE

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Specific conductance was measured weekly at all stations with a low of 51 µmhos/cm at Hastings Cove Brook and a high of 3377 µmhos/cm at Gates Brook (Worcester Street). Annual mean ranged from 137 µmhos/cm (Hastings Cove Brook) to 998 µmhos/cm (Gates Brook at Lombard Avenue). The highest values were seen during winter and spring and were related to snow and ice storms, salt applications, and elevated runoff. Conductivity values were also higher in most tributaries during the summer, fall, and early winter when flows were low.

Annual values in most tributaries were lower than the previous year, although differences were small and likely the result of increased flows due to a rainy year. Three tributaries had their highest annual median values ever; Muddy Brook and Waushacum Brook were only slightly higher than normal, but Malden Brook had an annual median value that was almost thirty percent higher than the previous two years. There was no concurrent rise in fecal coliform concentrations at these three tributaries, and fecal coliform concentrations in Malden Brook were at a historical low

Criteria were proposed by the DWM during the mid 1990s relating specific conductance and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100 mL are potentially impacted by septic systems. The impact is considered minor if less than eighty percent of samples exceed a specific conductance standard of 120 µmhos/cm, moderate if greater than eighty percent of samples exceed the 120 µmhos/cm standard, and severe if more than twenty percent of samples exceed a standard of 360 µmhos/cm. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. Stream flow appears to be directly related to conductivity, with "dry" years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason it is suggested that more than a single year be used in assessing these criteria.

An assessment of specific conductance and fecal coliform data from 2003 using the criteria described above found that ten of eighteen stations were likely contaminated by improperly functioning septic systems. Five of six stations on Gates Brook as well as the stations on West Boylston and Boylston Brooks were considered severely impaired. Problems along Gates Brook and West Boylston Brook have been well documented, and sewers have been constructed specifically to deal with this issue. The Boylston Board of Health recently confirmed that two homes near Boylston Brook have inadequate septic systems, and DCR staff are working with the Board of Health to remediate the problem. Water quality in the Quinapoxet River continues to decline and samples from both stations showed moderate impacts from septic systems. The Stillwater River showed minor impacts from septic systems. The Quinapoxet River and its tributaries were studied in depth during 2003 and the findings will be presented in the Quinapoxet District Environmental Quality Assessment Report during 2004. The Stillwater River and its tributaries will be studied during 2004 with an EQA Report to be published in 2005.

3.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done in the tributaries for a number of years. More than a decade of routine sampling in the tributaries had shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.5 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2003. Data have been collected from a number of locations over the past several years, but no clear seasonal trends have been determined, and presence or absence appear to be related more to precipitation, flow conditions, and presence of wildlife rather than season. Students from the University of Massachusetts continue to collect storm event samples as part of a study to help improve our understanding of the presence of these protozoa.

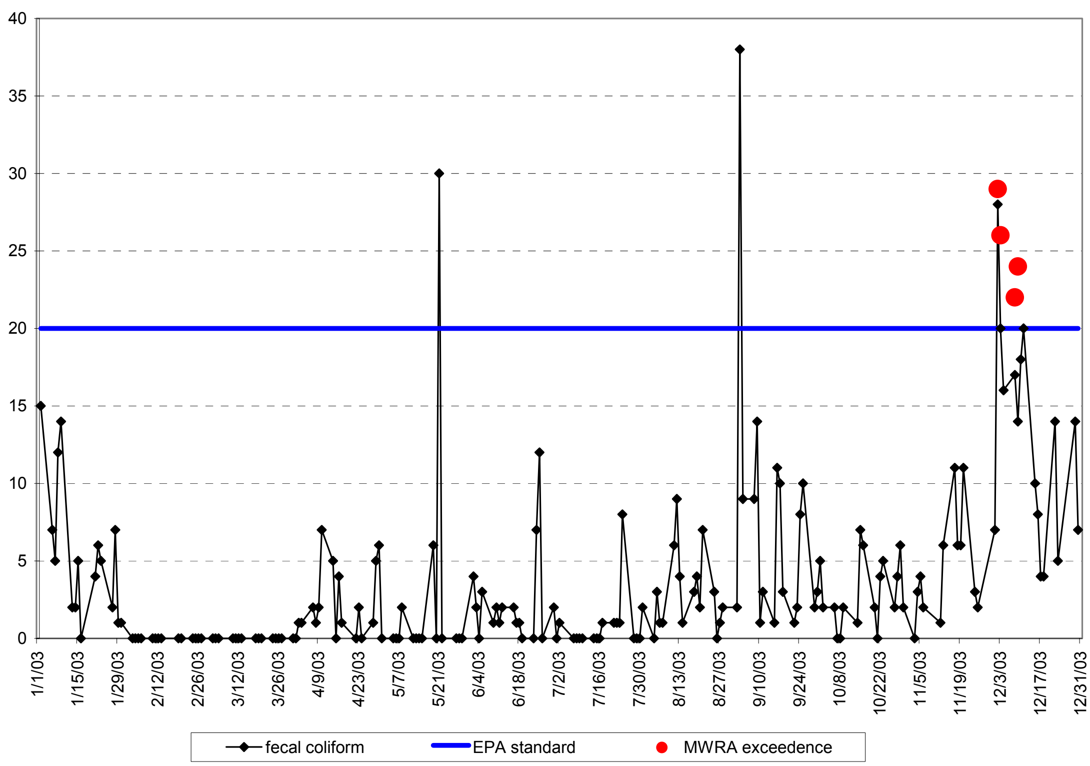
4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

4.1 BACTERIA

A total of 191 bacteria samples were collected at the Cosgrove Intake by Environmental Quality staff during 2003. A majority were surface samples collected from the back walkway or from a boat in close proximity to the intake. Forty samples collected between January 14th and April 1st were taken from an internal tap when ice formation around the intake structure precluded sampling by the other methods. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100 mL. More than ninety-eight percent of the samples collected at the Cosgrove Intake during 2003 contained less than the standard (Figure 3). The standard was exceeded only three times, on May 21st, on September 3rd following a day of rain, and on December 2nd. Problems caused by roosting gulls and other waterfowl were minimized due to a rigorous harassment program, but the exceedence in December was definitely related to bird activity. MWRA official compliance samples are collected from the internal tap and exceeded the standard four times during 2003, all during December after a stormy four day Thanksgiving weekend and before boat harassment became effective.

FIGURE 3

**COSGROVE INTAKE
FECAL COLIFORM CONCENTRATIONS (colonies/100mL)**



Bacteria samples were also collected at twenty-three additional surface stations across the reservoir to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese. Sample locations were illustrated on Figure 2. Samples were collected weekly, biweekly, or monthly after ice-out in April. All fecal coliform transect data are included in Table 18 on the following page.

Samples collected during April, May, June, July, and August contained low concentrations of fecal coliform. Only 63 of 118 samples contained any fecal coliform at all, and only three from mid reservoir contained 10 or more colonies per 100 mL. Concentrations increased at the southern end of the reservoir in September; six stations near the traditional roost area had samples with concentrations between 16 and 75 colonies per 100 mL. The fall increase in fecal coliform concentrations is a normal development that mirrors increases in the numbers of birds utilizing the reservoir for feeding, bathing, and roosting.

Bird harassment activities were intensified during mid September and October, and fecal coliform concentrations declined, with low numbers recorded at all reservoir stations. Many of the small lakes and ponds in the area began to freeze during November, and the number of gulls using the reservoir increased sharply. Concentrations of fecal coliform were elevated at most locations, especially at mid reservoir and at the southern end where birds have traditionally spent the night. By December fecal coliform concentrations were elevated at all stations and samples at 21 of 24 stations contained 20 or more colonies per 100 mL on December 4th. Although samples collected at the Cosgrove Intake contained fewer than 20 fecal coliform colonies per 100mL during all December transect sampling runs, regulatory samples collected by the MWRA did exceed the standard on four occasions. Intensive harassment using boats seven days per week reduced concentrations at the Cosgrove Intake and eventually at mid reservoir as well, but concentrations were still high until the end of the month. A total of 18 samples collected on December 9th exceeded the Class A standard of 20 colonies per 100 mL; this declined to 10 samples on December 17th and to only 8 by December 30th.

Fecal coliform concentrations did not exceed 100 colonies per 100 mL in any sample collected from the north end of the reservoir during 2003. Eleven samples at the south end of the reservoir did contain 100 or more colonies, all during December and all associated with large populations of roosting gulls. A maximum concentration of 660 colonies per 100mL was recorded from Station J-4 on December 23rd, and two other samples collected from the same location on different dates contained nearly 300 colonies per 100mL. The average of all transect samples collected in 2003 was twenty fecal coliform colonies per 100mL; the annual median was only five colonies per 100mL.

The 2003 bird harassment program was considered successful, even though there were four exceedences of the fecal coliform standard during December. Many birds appear to have adapted their flight patterns to avoid the north end of the reservoir entirely. A detailed summary of the harassment program with associated data is published weekly throughout the harassment season as part of the MWRA Weekly Water Quality Report.

TABLE 18

FECAL COLIFORM TRANSECT DATA - WACHUSETT RESERVOIR
2003

	04/23/03	05/14/03	06/18/03	07/17/03	08/28/03	09/25/03	10/07/03	10/23/03	11/12/03	11/25/03	12/04/03	12/09/03	12/17/03	12/23/03	12/30/03
Cosgrove	2	0	1	1	2	10	0	5	1	2	16	14	4	5	7
B-2	3	0	0	1	5	6	1	6	2	5	21	26	12	24	7
B-3	0	0	0	0	5	2	0	4	1	6	24	23	8	35	6
C-1	0	0	0	0	2	4	2	2	6	7	19	25	9	16	9
C-3	0	0	0	0	1	2	2	1	14	12	24	21	10	21	10
C-5	0	0	1	1	1	6	1	2	12	4	15	15	7	31	10
D-1	5	1	0	0	2	3	1	2	15	42	25	18	10	18	10
D-2	6	2	0	0	1	7	1	3	23	9	91	29	29	72	12
D-4	3	1	0	0	2	2	2	3	48	7	33	29	19	50	15
E-2	12	3	0	1	3	1	2	5	19	75	33	25	16	54	16
E-4	0	0	0	0	4	4	0	2	61	6	34	39	17	26	10
F-2	27	2	0	0	10	11	1	7	5	38	38	22	18	32	14
F-3	3	2	1	2	5	3	0	11	47	27	28	27	15	30	12
F-4	4	0	0	0	1	2	0	3	29	0	24	26	21	18	4
G-2	8	0	0	0	2	1	1	2	6	16	20	18	18	61	14
H-2	0	2	0	0	0	4	5	1	3	15	22	20	44	37	21
I-2	2	1	1	0	4	25	1	1	15	36	34	31	58	62	67
J-2	0	4	0	2	0	8	0	3	8	16	24	60	66	82	71
J-3	1	1	0	0	3	16	0	3	12	43	47	73	121	140	31
J-4	5	8	1	1	1	38	9	5	51	93	47	119	299	660	290
K-2	8	1	0	0	1	44	2	0	61	22	58	93	140	140	69
M-1	0	3	1	0	1	75	2	2	5	12	28	63	110	62	48
N-1	0	1	0	0	1	35	5	3	7	17	35	101	116	78	57
dam		0	0		2	10	1	2	1	2	26	15	4	12	4

4.2 WATER COLUMN CHARACTERISTICS

4.2.1 FIELD PROCEDURE

DCR staff routinely measure water column profiles in the Wachusett Reservoir for the following parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured weekly at Station 3417 (Basin North) in conjunction with plankton monitoring (see Section 4.4) and quarterly at the other key monitoring stations (Station 3412/Basin South and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a middle stratum characterized by a thermal gradient ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Profile measurement during the period of thermal stratification has two primary objectives: (1) to monitor phytoplankton growth conditions and detect "blooms" of potential taste and odor causing organisms associated with discrete strata of the water column (see Section 4.4) and (2) to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below). Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (now a component of the Hach Company located in Loveland, Colorado). These instruments are routinely charged and calibrated during the field season. At the conclusion of field work, data recorded by the logging system is downloaded to a PC as an Excel spreadsheet.

Station 3417 (Basin North) has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

4.2.2 THE QUABBIN "INTERFLOW" IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 2003, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in about 3 to 4 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a "short circuit" undergoing minimal mixing with ambient Wachusett Reservoir water.

A sustained transfer was initiated on June 30th and continued through October 16th. However, prior to sustained transfer, Quabbin water was transferred discontinuously at very low rates from June 4th to the 26th. After the sustained transfer ended on October 16th, transfers continued intermittently through December 8th.

A weak conductivity minimum was detected in front of the Cosgrove Intake on July 25th (see Specific Conductance section below) indicating completion of interflow penetration through the main basin in a period of 25 days from transfer initiation. This penetration interval was slower by about 4 days than predicted according to regression analysis of data from previous years.

The likely cause of this delay was the preliminary weak transfer that occurred from June 4th to the 26th prior to initiation of sustained and robust transfer. At its conclusion on June 26th the preliminary weak transfer amounted to a volume nearly equal to the volume of Thomas Basin and functioned to partially flush out that basin with cold Quabbin water and weaken or disrupt the usual seasonal development of thermal stratification. As a result, when sustained transfer was initiated, the transfer water inevitably underwent an initial period of mixing with water in Thomas Basin instead of passing through rapidly as a dense, discrete underflow as is typical. A review of transfer records as far back as 1995 indicate there have been no other years when initiation of a sustained and robust transfer was proceeded by a preliminary period of discontinuous weak transfers.

By mid-August, the interflow stratum had developed into its usual configuration with a thickness of nine meters forming between 6 and 15 meters deep. At the conclusion of 2003, the transfer volume totaled 161 million cubic meters, equivalent to 65 percent of the Wachusett basin volume. The influence of the 2003 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

4.2.3 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Station 3417 (Basin North) is depicted in Figure 4 on the following page.

An early stage of thermal stratification was evident on the May 22nd measurement date when a difference of approximately seven degrees C existed between the top and bottom of the water column. The top of the water column continued to gain heat and a fairly uniform gradient from 21° C at the surface extending down to around 10° C at a depth of 14 meters is evident on June 24th.

The establishment of the interflow from Quabbin (see section 4.2.2 above) can been seen in the profile measured on August 20th. A very steep thermal gradient exists between depths of five and seven meters in which the temperature dropped approximately 10° C. Similarly, the profile measured on September 3rd shows a thermocline (defined as a temperature gradient of 1° C per meter or greater) beginning at a depth of 6 meters and falling steeply to temperatures characteristic of the Quabbin interflow. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between depths of approximately 6 and 15 meters.

The presence of the Quabbin interflow was also evident in the temperature profiles as a pronounced flattening or plateau in the thermocline between 10 and 13 meters where the temperature centers around 13° C. This plateau represents the “core” of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

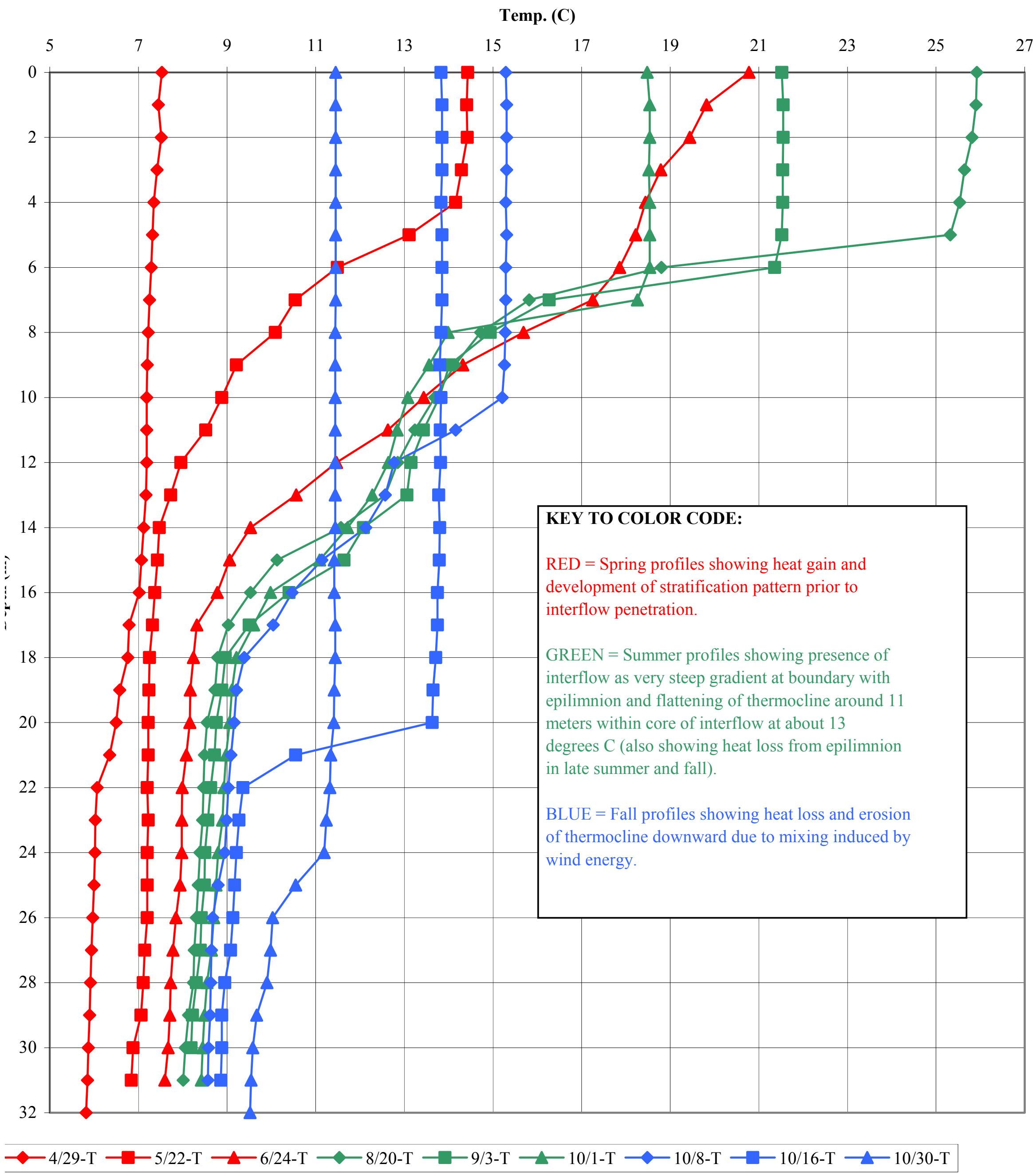
Highest temperatures in the epilimnion were recorded in July at about 27° C while temperatures in the hypolimnion remained at about 9° C throughout the summer. In late August, the system began to lose heat as air temperatures cooled and radiation intensities diminished.

The profile measured on October 8th shows that heat losses and wind energy had eroded the thermocline downward into the metalimnetic interflow and mixed it with the epilimnion down to a depth of 10 meters. A forceful wind storm on October 15th caused the water column to be mixed down to a depth of 20 meters thus homogenizing the epilimnion, the remainder of the metalimnetic interflow stratum, and the upper portion of the hypolimnion.

By October 30th, a difference of less than 2° C existed between the top 24 meters of the water column and the remnant hypolimnion occupying the bottom 8 meters of the water column. Soon after the October 30th measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column, in an event known as fall “turnover”. Profiles recorded on November 18th show the water column to be essentially isothermal at slightly over 8° C.

Figure 4

2003 Water Column Profiles of Temperature
Basin North/Station 3417



4.2.4 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 65 to 100 percent saturation for ambient water temperatures. Saturation values in the epilimnion remained above 80 percent throughout the year, whereas saturation values in the metalimnion and hypolimnion from May through October fall progressively lower (Figure 5).

During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to between 55 and 60 percent saturation before fall turnover in early November replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

Maximum dissolved oxygen saturation values of over 100% were observed at the boundary between epilimnion and metalimnetic interflow at depths of four to five meters for about two weeks in July. The sharp thermal gradient at this boundary in combination with other factors evidently triggered intense photosynthetic activity by phytoplankton concentrated in this narrow vertical stratum. The release of oxygen associated with this activity resulted in the spike of high saturation values measured on these dates.

The profile measured on October 16th shows homogenization of the water column down to 20 meters effected by a forceful wind storm on the previous day. This storm replenished oxygen to greater than 80 percent saturation throughout the mixed volume. In early November, wind energy dispersed the remnant stratification pattern mixing and exposing the entire basin volume to the atmosphere thereby replenishing dissolved oxygen concentrations at all depths. Profiles recorded on November 18th show dissolved oxygen registered at or above 80 percent saturation at all depths.

4.2.5 SPECIFIC CONDUCTANCE

Specific conductance ("conductivity") profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 µS/cm with an average value between 125 and 150 µS/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 µS/cm. Typically during periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin range from 75 to 125 µS/cm depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 6 depicts conductivity profiles measured at Station 3417 (Basin North) from June through October.

Figure 5

2003 Water Column Profiles of Dissolved Oxygen Percent Saturation
Basin North/Station 3417

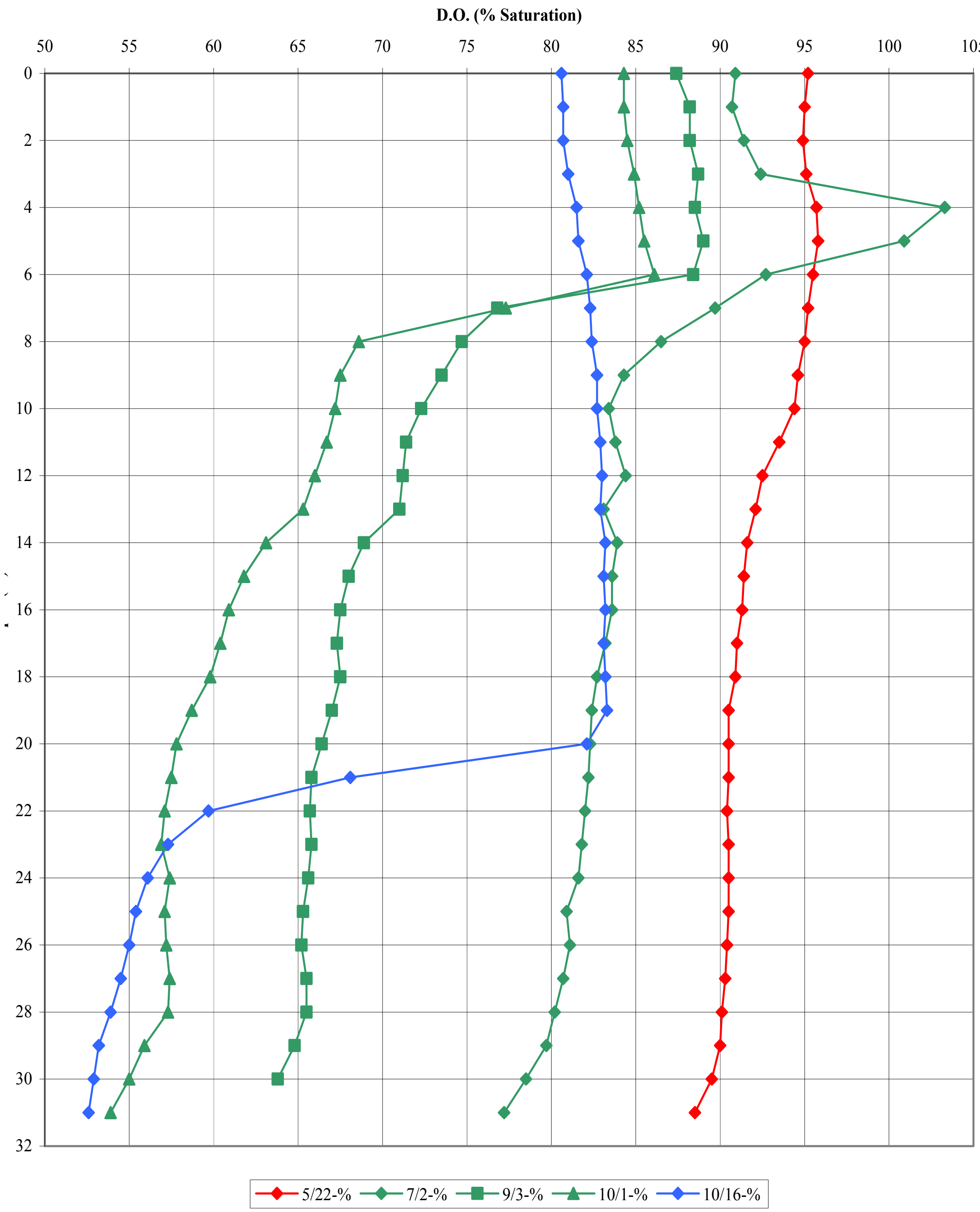
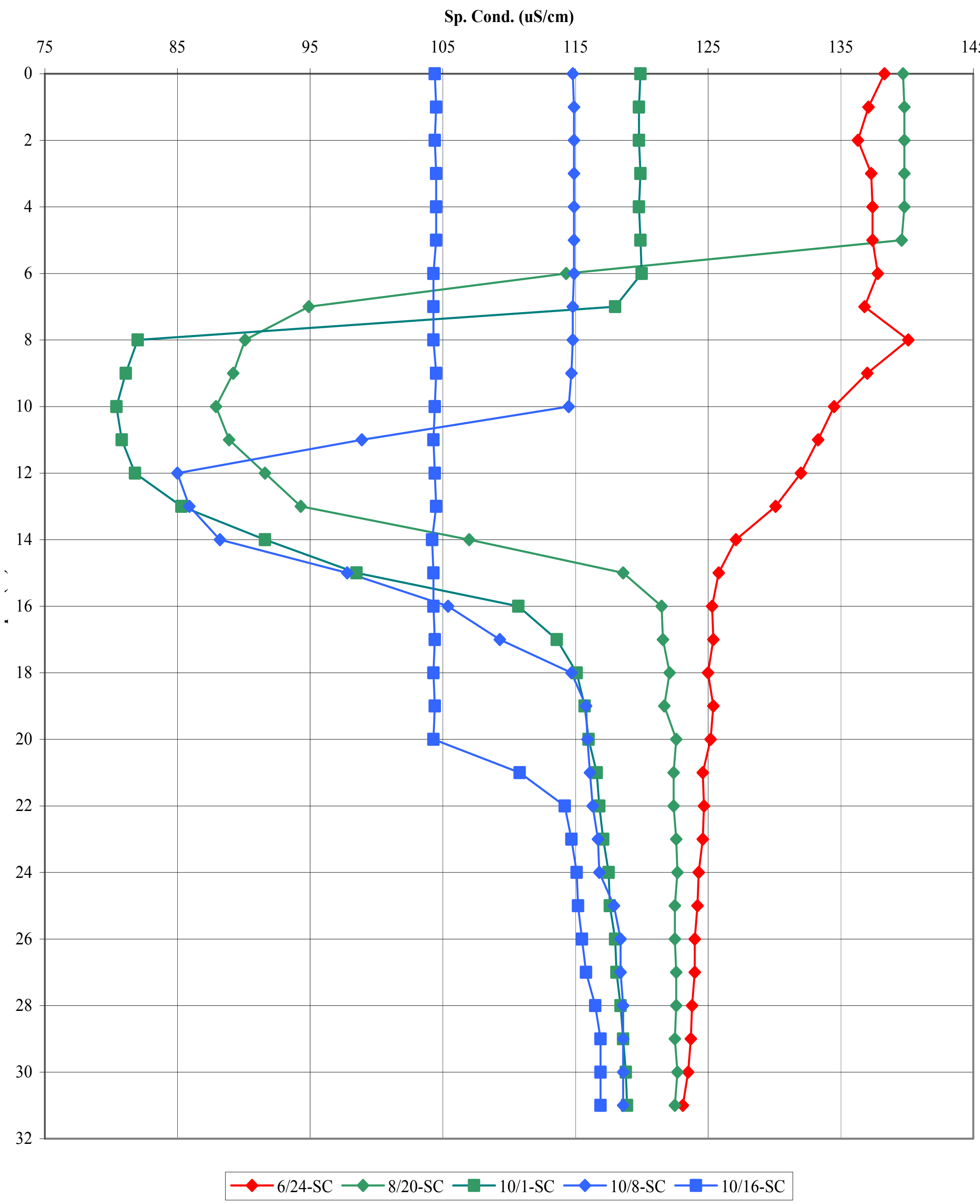


Figure 6

2003 Water Column Profiles of Specific Conductance
Basin North/Station 3417



On June 24th, before the Quabbin transfer had been initiated, conductivity values ranged between 123 and 140 µS/cm throughout the water column. The profiles recorded on August 20th and October 1st show the development of the interflow stratum as a "trough" in the conductivity profile between depths of around 6 and 15 meters. This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. By October 1st a minimum interflow conductivity value of about 80 µS/cm was observed at a depth of 10 meters at Station 3417.

Profiles measured on October 8th show that heat losses and wind energy had caused the water column to be mixed down to a depth of 10 meters. The conductivity of the stratum resulting from the homogenization of the epilimnion and the top portion of the metalimnetic interflow was 115 µS/cm. The profile measured on October 16th shows homogenization of the water column down to 20 meters effected by a forceful wind storm on the previous day. The conductivity of the stratum resulting from the homogenization of the epilimnion, the remainder of the metalimnetic interflow stratum, and the upper portion of the hypolimnion was approximately 105 µS/cm.

In early November, wind energy dispersed the remnant stratification pattern and mixed the entire water column. By November 18th, with the Quabbin transfer continuing to dilute the Wachusett water column, a conductivity value of approximately 102 µS/cm was measured uniformly throughout.

4.2.6 HYDROGEN ION ACTIVITY (pH)

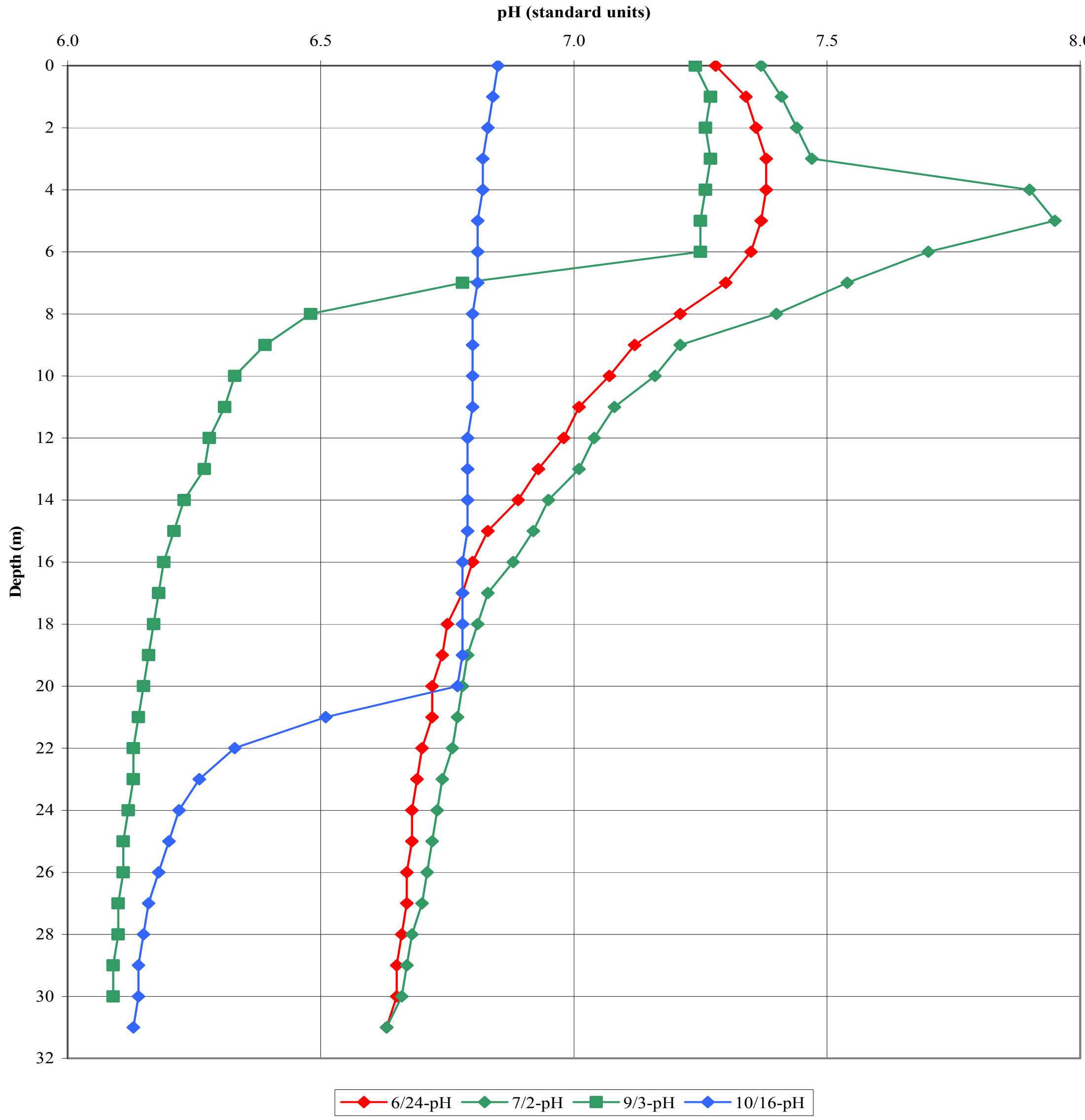
Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 7 depicts pH profiles measured at Station 3417 (Basin North) from June through October.

Photosynthesis by phytoplankton results in the uptake of carbon dioxide dissolved in the water. The uptake of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Maximum pH values around 7.9 were observed around the boundary between epilimnion and metalimnion at depths of four to five meters for about a two week period in July. As discussed above in relation to the dissolved oxygen maximum, a short period of intense photosynthetic activity by phytoplankton concentrated at this depth was evidently triggered by the sharp thermal gradient in combination with other factors.

Photosynthetic activity maintained epilimnetic pH in the range between 7.1 and 7.3 through early September. Values of pH ranging from 6.2 to 6.8 were measured in the metalimnion during the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir.

Figure 7

2003 Water Column Profiles of Hydrogen Ion Activity (pH)
Basin North/Station 3417



In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. By September, pH values in the hypolimnion had decreased to values around 6.1. A forceful wind storm on October 15th caused the water column to be mixed down to a depth of 20 meters with pH values around 6.8 resulting in the mixed stratum. Wind energy dispersed the stratification pattern at turnover with resulting pH values between 6.8 and 7.0 measured uniformly throughout the water column on November 18th.

4.3 NUTRIENTS

4.3.1 FIELD PROCEDURE

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (July), near the end of the stratification period (October), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main monitoring stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in the recent comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003). Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.05 mg/L from previous limits of 0.2 and 0.6 mg/L) and the addition of UV254 absorbance among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as is a relative assay of the concentrations of organic compounds dissolved in the water.

4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2002 is used as a basis for interpreting data generated in 2003. Results of quarterly nutrient sampling in 2003 document concentrations that generally register within or close to historical ranges. (Table 19; see complete quarterly database in Appendix).

A few of the values of ammonia, nitrate, and UV254 absorbance measured in 2003 were notable in registering slightly higher than the ranges observed in the 1998-02 historical database. Almost all these higher values were measured in the samples collected in May. The occurrence of these higher values in May reflect the linkage of Wachusett Reservoir to Quabbin Reservoir as described in the paragraphs that follow.

Table 19 - Wachusett Reservoir Nutrient Concentrations:

Comparison of Ranges from 1998-02 Database[1] to Results from 2003 Quarterly Sampling [2]

Sampling Station [3]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-02	Quarterly'03	1998-02	Quarterly'03	1998-02	Quarterly'03	1998-02	Quarterly'03	2000-02	Quarterly'03
Basin North/3417 (E)	<5 - 12	<5 - 12	<5 - 124	47 - 159	0.59 - 3.02	1.67 - 2.77	<5 - 13	7 - 12	0.032 - 0.068	0.051 - 0.072
Basin North/3417 (M)	<5 - 36	<5 - 29	<5 - 138	46 - 164	0.77 - 3.31	1.87 - 2.82	<5 - 17	7 - 10	0.032 - 0.079	0.051 - 0.076
Basin North/3417 (H)	<5 - 41	11 - 33	48 - 190	80 - 202	1.27 - 3.92	2.36 - 3.80	<5 - 14	7 - 9	0.032 - 0.069	0.056 - 0.064
Basin South/3412 (E)	<5 - 14	<5 - 14	<5 - 172	54 - 162	0.56 - 3.84	1.84 - 3.09	<5 - 17	7 - 9	0.031 - 0.085	0.050 - 0.079
Basin South/3412 (M)	<5 - 26	<5 - 39	11 - 184	78 - 162	0.95 - 4.03	2.10 - 2.88	<5 - 22	7 - 10	0.032 - 0.089	0.053 - 0.074
Basin South/3412 (H)	<5 - 44	14 - 32	49 - 224	94 - 184	1.64 - 4.13	2.93 - 3.53	<5 - 37	7 - 14	0.036 - 0.091	0.052 - 0.073
Thomas Basin (E)	<5 - 18	<5 - 17	<5 - 201	57 - 170	0.62 - 5.00	1.88 - 3.60	<5 - 23	10 - 17	0.026 - 0.140	0.064 - 0.143
Thomas Basin (M)	<5 - 18	<5 - 27	<5 - 205	59 - 190	0.88 - 4.94	1.68 - 3.84	<5 - 22	8 - 16	0.026 - 0.147	0.065 - 0.150
Thomas Basin (H)	<5 - 21	5 - 24	<5 - 236	39 - 163	0.92 - 4.99	1.49 - 4.25	<5 - 22	11 - 24	0.027 - 0.150	0.040 - 0.200

Notes: (1) 1998-02 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2002, except for measurement of UV254 initiated in 2000 quarterly sampling

(2) 2003 quarterly sampling conducted May, July, October, and December

(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

Nutrient concentrations in Wachusett Reservoir are influenced by a variety of factors that fluctuate annually including amounts of runoff (rain and snowmelt) discharged from the watershed, nutrient loading rates associated with the runoff, and population dynamics of phytoplankton. Overriding these factors, however, is the timing and duration of the Quabbin transfer. Water quality within the reservoir basin reflects a dynamic interaction between the influences of the Wachusett watershed and the Quabbin transfer. The Quabbin transfer is characterized by water of very low nutrient concentrations whereas the influence of the Wachusett watershed is exerted mostly via the discharges of the Quinapoxet and Stillwater Rivers with higher nutrient concentrations.

The interplay between these two influences results in slight shifts in the range of nutrient concentrations from one year to the next. In three of the previous four years (not in 2000) the peak period of transfer from Quabbin occurred from May through December. In 2003, a sustained transfer was not initiated until June 30th. Samples collected in May of 2003 had relatively elevated nutrient concentrations because discharges from the Quinapoxet and Stillwater Rivers had greater proportional influence prior to entry of the Quabbin transfer. This corresponds exactly to the temporal distribution of maximum nutrient concentrations observed in 2000 when the Quabbin transfer was not initiated until June 28th. These interannual patterns of nutrient dynamics are analyzed in detail in the recent comprehensive report (Worden and Pistrang, 2003).

In conclusion, the slightly higher concentrations observed in May 2003 reflect strong watershed influence and a correspondingly diminished proportion of Quabbin derived water occupying the basin due to late initiation of the transfer. Other than the slight increases in the ranges of nutrient concentrations discussed above, the patterns of nutrient distribution in 2003 quarterly samples were comparable to those documented in the recent comprehensive report (Worden and Pistrang, 2003). These patterns consist most importantly of the following: (1) prominent seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter, (2) interannual fluctuations in nutrient concentrations and parameter intensities occurring across the main basin as a result of the divergent influences of the Quabbin transfer and the Wachusett watershed with temporary lateral gradients becoming pronounced for nitrate, silica, UV254, and conductivity, either increasing or decreasing downgradient of Thomas Basin depending on the dominant influence. Future nutrient sampling at Wachusett Reservoir will continue on a quarterly schedule.

4.4 PHYTOPLANKTON

New staff assignments and procedures for phytoplankton monitoring were initiated in 2003. The previous method of collecting grabs at various depths from the catwalk at the rear of Cosgrove Intake was replaced by sampling from a boat at Station 3417 (Basin North) during the late-April through early-November thermal stratification period. Station 3417 is representative of the deepest portion of the basin and it is not influenced by seiche effects or turbulence from water withdrawals which can destabilize stratification boundaries and obscure associated phytoplankton growth patterns at Cosgrove Intake. However, samples collected at Cosgrove are adequately representative of the main basin during the late-November through early-April period of mixis when the water column is homogenous, so sampling was conducted from the catwalk during this period ice conditions permitting.

Samples were generally collected at two depths: (1) near the middle of the epilimnion at three meters and (2) near the top of the metalimnetic interflow stratum at eight meters (also corresponding to the upper intake depth). Additionally, samples were collected at specific strata within the water column supporting intense growth or activity by phytoplankton as indicated by spikes in dissolved oxygen concentrations (a "positive heterograde curve") measured in the field with a Hydrolab multiprobe. Samples were collected using a Van Dorn Bottle and returned to the laboratory for concentration and microscopic analysis.

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. The method of sand filtration for concentration of phytoplankton samples has long been in use by both MWRA and DCR because it enables relatively rapid analysis of samples while subjecting organisms to minimal damage or distortion. The specific method used is documented in Standard Methods Twelfth Edition (1965, pages 669-671; photocopies kindly provided by Warren Zepp of MWRA). In brief, the method entails gravity filtration of sample water placed in a funnel through a layer of fine sand followed by washing and gentle shaking of the sand with waste filtrate water in a beaker to detach organisms from the sand grains, and lastly, prompt decanting of the concentrated sample after the sand has been allowed to settle. A portion of the concentrated sample is then analyzed microscopically using quantitative techniques as presented below.

Phytoplankton taxa in concentrated samples were enumerated using a Sedgewick-Rafter (S-R) Cell which enables phytoplankton densities to be quantified. Each concentrated sample was mixed to homogenize the sample and then 1 ml of the sample was withdrawn with a pipette and placed into the S-R Cell. Initial inspection of phytoplankton within the S-R Cell was accomplished with a stereozoom dissecting microscope capable of magnification from 7 to 45 times. Use of this instrument to scan the entire S-R Cell was important to detect colonies of certain motile taxa present at low densities such as *Synura* and/or colonies floating against the underside of the coverslip such as *Anabaena*.

Microscopic analysis of phytoplankton samples was performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Approximately 15 minutes were allowed for the phytoplankton to settle to the bottom of the S-R Cell before enumeration. Phytoplankton were enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields were selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

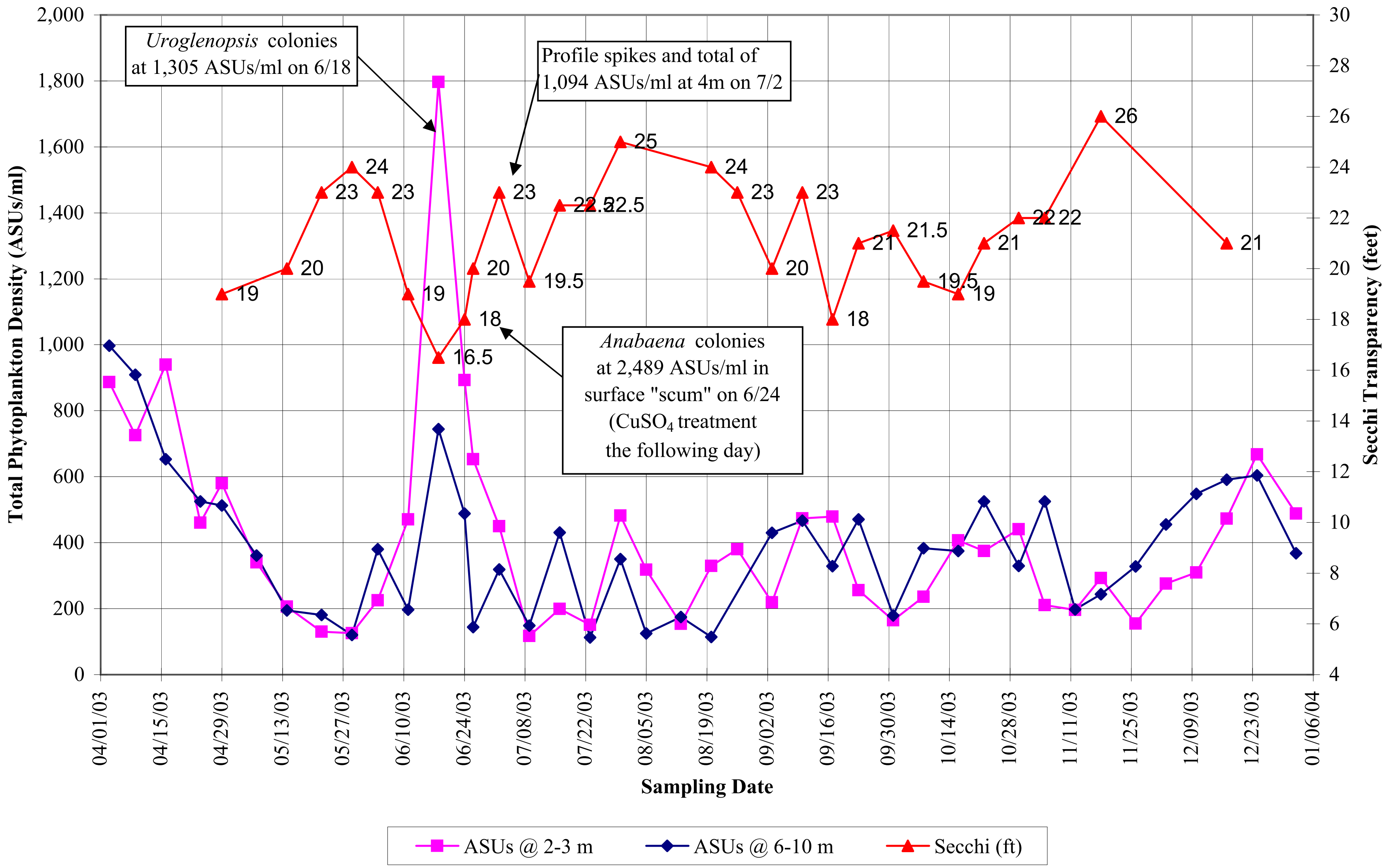
Phytoplankton densities were expressed as Areal Standard Units (ASU; equivalent to 400 square microns). The area of each specimen viewed in each counting field was estimated using the ocular micrometer (the ocular field was divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASU at 200X magnification). In the case of taxa which form gelatinous envelopes or are enclosed in a colonial mucilage, such as *Microcystis*, the area of the envelope was included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, was estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates, were not included in the count.

Monitoring results for 2003 document an annual cycle of phytoplankton succession that is consistent with historical data. This successional cycle is composed of broad patterns characteristic of many temperate, oligotrophic systems, but also includes features unique to the phytoplankton of Wachusett Reservoir. The broad patterns consist of the following: minimal activity in winter due to low temperatures and light intensities, a spring maximum dominated by diatoms, a summer minimum following the spring depletion of nutrients, a secondary peak in the fall, and then a return to low winter densities. Additional successional features unique to Wachusett Reservoir include an epilimnetic bloom of chrysophytes as well as a surface bloom of *Anabaena* both occurring in June. Details of phytoplankton succession in 2003 are given below.

Diatoms bloomed in the spring after ice-out and contributed to a maximum total density of 997 ASU/mL on April 3rd before declining steadily through mid-May (Figure 8). The chrysophyte *Uroglenopsis* was first detected on June 4th at low densities in the epilimnion (113 ASU/mL), but by June 18th had rapidly increased to a density of 1,305 ASU/mL. Diatoms composed most of the remainder of the annual maximum of 1,797 ASU/mL recorded on this date (Figure 8). Large colonies of *Uroglenopsis* suspended in the water were visible to the unaided eye at this time and, not surprisingly, the minimum annual Secchi transparency measurement of 5 meters (16.5 feet) coincided with this bloom.

Also present on June 18th were colonies of *Anabaena* consisting of spherical "clumps" of filaments. These colonies were observed at low densities (4 – 28 ASU/mL) and each colony had numerous specimens of the stalked protozoan *Vorticella* (Ciliophora) attached. In the week following June 18th, densities of *Uroglenopsis* declined precipitously while the *Anabaena* population grew rapidly. On the morning of June 24th, the reservoir surface was completely calm due to lack of wind and the day was already hot under a bright sun. Close inspection of the reservoir surface showed it to be peppered with green specks over extensive areas. A sample of this surface "scum" representing the top 3 cm of the water column was collected in addition to conventional samples at depth and analysis of the “scum” sample documented *Anabaena* colonies at a density of 2,489 ASU/mL.

Figure 8
Phytoplankton and Secchi Transparency: Weekly Monitoring in 2003



These very high *Anabaena* densities were restricted to the surface of the water column and likely resulted from colonies floating to the surface over a period of many hours when the lack of appreciable wind and associated mixing enabled them to accumulate. Densities at 0.2, 3, and 8 meters ranged from zero to 30 ASU/mL; the "scum" density is not depicted in Figure 8. Records from the meteorological station at Cosgrove Intake indicate average wind speeds of only 1.26 mph in the first ten hours of June 24th and average wind speeds of less than 0.5 mph in the four hours proceeding scum sampling at around 10am.

Anabaena is an organism with the potential to cause taste and odor problems, so MWRA immediately mobilized for copper sulfate application which was conducted on June 25th in the "treatment area" adjacent to Cosgrove Intake. Post-application monitoring on June 26th showed the *Anabaena* bloom to be almost completely dissipated with densities ranging from zero to 32 ASU/mL at all depths both within and outside the "treatment area" where copper sulfate was applied. This indicates that the bloom was extinguished by natural causes, likely from intense heat and ultraviolet radiation at the surface, in addition to copper sulfate toxicity within the "treatment area". Calm, hot, and sunny conditions cannot be relied upon for the demise of future *Anabaena* blooms, however, because winds can rapidly mix surface blooms downward to depths at which they may enter the intake.

In early July, prior to penetration of the interflow, spikes in dissolved oxygen concentration and hydrogen ion activity (pH) in profile measurements indicated increased photosynthetic activity where organisms had aggregated in the steepest portion of the thermocline at a depth of around 4 meters. Sampling at this depth showed the organisms responsible for this activity to be mostly diatoms and *Dinobryon* reaching a total density of 1,094 ASU/mL.

After the two bloom events in June and brief aggregation of organisms at the top of the thermocline in early July, phytoplankton activity subsided. Between July and September populations of chlorophytes, cyanophytes, and diatoms fluctuated at relatively low densities. In September and early October, diatoms were frequently observed at higher densities at 8 meters than at 3 meters. This disparity in diatom densities is likely due to the presence of Quabbin specimens (mostly *Asterionella*) transported in the interflow at 8 meters. A minor bloom of *Microcystis* persisted from mid- to late October with densities ranging around 200 ASU/mL.

Beginning in November, diatoms resumed their dominance among phytoplankton taxa, but remained at low densities. The maximum annual Secchi transparency measurement of 7.9 meters (26 feet) was observed on November 18th. Diatom populations grew steadily through November and December contributing to a maximum total density of 668 ASU/mL on December 24th. Diatom densities had declined somewhat by January 2nd before ice conditions terminated further monitoring efforts.

4.5 MACROPHYTES

4.5.1 THE THREAT OF EURASIAN WATER-MILFOIL

The Wachusett Reservoir system is a major component of the drinking water supply for greater Boston. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum;* referred to subsequently as "milfoil") was observed for the first time in Upper Thomas Basin, a small basin in the upper reaches of the reservoir system. Milfoil is an exotic, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of milfoil into Upper Thomas Basin represents a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient "pumps", extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

This function is especially intense with milfoil due to its characteristically rapid and prolific growth habit. Nutrient release occurs during most life cycle stages, but especially during senescence and death. Milfoil also releases nutrients and organic matter during canopy formation (lower leaves and branches are sloughed as upper stems grow horizontally along the surface) and when undergoing a propagation process known as autofragmentation. Autofragments are stem segments with adventitious roots at the nodes that float upon abscission and are the plant's most important mode of reproduction and dispersal. Autofragments of milfoil eventually sink to the bottom and are capable of colonizing littoral zone areas having only minimal deposits of organic sediment.

4.5.2 WACHUSETT RESERVOIR MILFOIL CONTROL PROGRAM

The 2001 expansion of milfoil into Upper Thomas Basin prompted DCR to design a milfoil control program which was implemented in 2002. A description of the 2002 milfoil control program is described in the annual report for that year. Milfoil control efforts in 2003 consisted of a continuation of the main control technique of hand-harvesting as well as implementation of a biological control program using the milfoil weevil according to plans formulated in 2002. Hand-harvesting was conducted by Aquatic Control Technology (ACT) of Sutton, MA and weevil introduction was conducted by GeoSyntec Consultants of Boxborough, MA with oversight and assistance provided by DCR. Details of these components of the 2003 milfoil control program are summarized on the following page.

Hand-Harvesting of Eurasian Water-milfoil: Summary of ACT Efforts

- preliminary reconnaissance and GPS survey of Upper Thomas Basin conducted on May 23rd and 30th respectively
- hand-harvesting conducted during eight days between June 30th and September 10th mainly focused on Upper Thomas Basin, but also including Thomas Basin proper
- total diver-hours expended = 93.25 (compared to 496.5 hours in 2002)
- estimate of total plants removed = 3,251 (compared to estimate of 75,000 - 100,000 plants removed in 2002)
- post-harvesting surveys of targeted areas on September 25th and 30th document nearly total control of milfoil (also routine scouting by DCR finds no milfoil in main basin)

Biological Control of Eurasian Water-milfoil: Weevil Introduction by GeoSyntec

- initial reconnaissance of Stillwater Basin conducted on June 19th (select single stocking site and control site); weevil stocking conducted on June 26th (10,000 weevils, mostly in the form of eggs and larvae)
- post-stocking survey of Stillwater Basin conducted August 21st
- lab analysis of milfoil stem samples indicates presence of pre-existing weevil population in contrast to pre-stocking assessment of "no significant evidence" of weevil herbivory based on observations in the field
- based on lab results weevil stocking project "represents an augmentation" of an existing population, but post-stocking field observations document significant damage to milfoil at stocking site while milfoil at control site remains vigorous
- at stocking site lab evidence of damage to stems increases from 43% pre-stocking (13 of 30) to 100% post-stocking (30 of 30)
- at control site lab evidence of damage to stems increases from 13% pre-stocking (4 of 30) to 30% post-stocking (9 of 30)

In addition to the activities of consultants summarized above, DCR staff deployed floating fragment barriers (purchased in 2002) at strategic locations to restrict the movement of milfoil autofragments into downgradient portions of the reservoir system. These locations are where floating fragment barriers were initially deployed in 2002 and consist of the railroad bridge "bottleneck" between Stillwater Basin and Upper Thomas Basin and the Beaman Street Bridge "bottleneck" between Upper Thomas Basin and Thomas Basin proper. In 2003, floating fragment barriers were deployed in May and retrieved in late October.

4.5.3 PLANS FOR MILFOIL CONTROL EFFORTS IN 2004

It is evident from the greatly reduced diver-hours required for hand-harvesting suppression of milfoil in 2003 that this technique can effectively "keep up" with milfoil dispersal and regrowth in Upper Thomas Basin. Many fewer plants were removed in 2003 compared to 2002 in the process of achieving nearly complete elimination of milfoil within this component of the reservoir system.

Milfoil will inevitably recolonize Upper Thomas Basin, however, and must be targeted for continued hand-harvesting efforts over the long-term to prevent its dispersal throughout the main body of Wachusett Reservoir. Associated with hand-harvesting efforts, frequent scouting for milfoil throughout the reservoir system will be continued by DCR to identify and target any pioneering specimens found in new areas. Scouting and hand-harvesting will be sustained as long as milfoil is evident anywhere in the system downgradient of Stillwater Basin. Also next year, the floating fragment barriers will be redeployed by DCR staff as done in 2003. Finally, removal of a few of the benthic barrier panels installed in 2002 is planned as a first step in restoring littoral zone habitat to its natural state now that the milfoil infestation in this portion of Upper Thomas Basin has been suppressed.

The biological control program in Stillwater Basin will continue in 2004 in the form of a post-introduction survey conducted by the contractor, but will not include any additional weevil introductions. The post-introduction survey in 2004 will indicate the success of the weevils in over-wintering and monitor the grazing impacts of their population on milfoil in the stocking and control sites.

5.0 SUMMARY OF SITE INVESTIGATIONS

A total of 101 sites were investigated during 2003. A majority of the issues at these locations were related to residential development (45), commercial development (16), stormwater management (7), or spills of hazardous materials (7). Other problems addressed included road reconstruction, wetland encroachment, faulty septic systems, fecal contamination by wildlife, construction of parking lots, dumping, and sedimentation from sewer construction.

Problems at forty-six of the sites were addressed during 2003 and are now considered resolved. Twenty-one sites are currently on watch status. Work at these sites is being monitored and additional activities are necessary in some cases, but the Office is confident that successful resolution of these issues will occur. Problems at these sites are associated with commercial construction (drug store, greenhouse, parking lots), bridge replacement, residential construction (additions, garages, single-family homes), cleanup of gasoline releases, and agricultural operations.

Thirty-four sites remain active. Twelve involve residential construction issues, from minor additions to large subdivisions and a 40-unit townhouse complex. Seven of the sites involve commercial development, including a new warehouse and two auto body shops. Office staff continue to work with local officials and with the developers to try and find ways to allow appropriate development. Three bridge repairs and a road reconstruction project are underway and under review. Four sites with failing or suspect septic systems are being investigated. The Boards of Health in Boylston and West Boylston have been contacted; a study involving alternative indicator organisms and additional routine sampling is ongoing at one of the sites and has been described previously. Other issues include dumping of railroad ties, an illegal discharge from a basement, work within a wetland, problems with sedimentation from sewer construction, and a parking area too close to a municipal wellhead.

6.0 SAMPLING PLAN FOR 2004

The Wachusett watershed sampling program for 2004 will once again include special studies, enforcement actions, incident response, and routine sampling and analysis. The routine sampling program will attempt to separate out the effects of storm events on tributary and reservoir water quality from standard dry weather water quality data using detailed precipitation data from five stations in or near the watershed. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform and conductivity will be measured weekly at fifty-three stations on thirty tributaries during dry weather. This is a significant expansion of the sampling program that has been in place for the past few years and is an attempt to collect data from a greater number of stations to be able to address issues that have been identified in previous water quality summaries and Environmental Quality Assessment reports. Quarterly nutrient samples will again be collected from nine tributary stations with available flow data. Separate wet weather sampling of eight major tributaries will be done to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then the eight stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries.

Fecal coliform bacteria samples will be collected daily four days per week at the Cosgrove Intake, the Wachusett Dam, and from the Route 12 Bridge at the upper end of the reservoir when ice conditions allow. Monthly temperature, dissolved oxygen, pH, and conductivity profiles will be taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Algae samples will be collected weekly or biweekly at multiple depths from the Cosgrove Intake or mid reservoir station 3417, and quarterly from Thomas Basin and mid reservoir station 3412. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and silica will be collected quarterly from 3417, 3412, and Thomas Basin.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly bacterial transect sampling will be done during ice-free periods to help further understand the effect of water movement on fecal coliform levels throughout the reservoir.

A study of the movement of pathogens during storm events was initiated by UMASS in 2002 with funding from the American Water Works Association Research Foundation and the cooperation of the DCR Office of Watershed Management. The study is designed to look at different land uses (agriculture, residential, forest) and determine how best to monitor pathogens and their movement through the watershed during both wet and dry conditions throughout the year. This information will be used to optimize future sampling programs and to more accurately predict potential public health problems. Office staff have supported this work by collecting samples, maintaining field equipment, and performing bacterial analyses. Continued work on the study is planned through the spring of 2004, and an extension of the study is being considered in order to collect data from additional storm events.

Sampling of the Pinecroft area drainage basin will continue in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small subbasin at the headwaters of Gates Brook prior to sewer construction. Sewers are now in the ground and many of the homes in the area have been connected. Improvements in water quality are expected. Additional areas in the watershed that have recently been sewered will also be examined to see if improvements can be detected.

Additional sampling recommended in two previously published Environmental Quality Assessment Reports (Reservoir, Thomas Basin) and in the Quinapoxet Environmental Quality Assessment Report (in press) will be done during 2004, along with sampling to support the Stillwater Environmental Quality Assessment. This additional sampling is the primary reason for the expansion of the routine weekly program as described in the second paragraph of Section 6 on the previous page.

Reference Cited:

Worden, David and Larry Pistrang. 2003. Nutrient and Plankton Dynamics in Wachusett Reservoir: Results of the MDC/DWM's 1998-2002 Monitoring Program, a Review of Plankton Data from Cosgrove Intake, and an Evaluation of Historical Records. Metropolitan District Commission, Division of Watershed Management.